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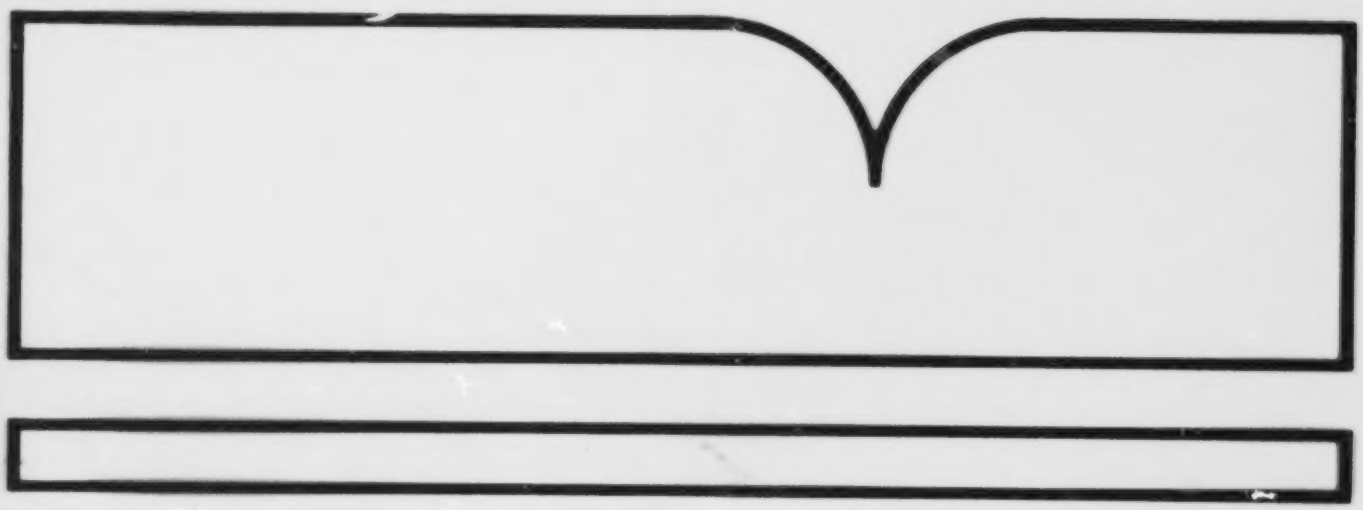

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This report focuses on the manufacture of chlorofluorocarbons and the precursor chemicals. It is a support document for the Rand Corporation study: Adele R. Palmer, et. al., Economic Implications of Regulating Nonaerosol Chlorofluorocarbon Emissions, R-2524-EPA.

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This document is a support document for a contractor's study done with the supervision and review of the Office of Pesticides and Toxic Substances of the U.S. Environmental Protection Agency. The purpose of the main study was to evaluate the economic implications of alternative policy approaches for controlling emissions of chlorofluorocarbons (CFCs) in the United States.

The support document was submitted in fulfillment of Contracts No. 68-01-3882 and 68-01-6111 by the contractor, The Rand Corporation, and by its subcontractor, International Research and Technology, Inc. Work was completed in August 1980.

The study is not an official EPA publication. The document can not be cited, referenced, or represented in any court proceedings as a statement of EPA's view regarding the chlorofluorocarbon industries, or of the impact of the regulations implementing the Toxic Substances Control Act.

PREFACE

Scientific studies indicate that atmospheric emissions of chlorofluorocarbons (CFCs) contribute to depletion of the ozone layer that protects the earth from harmful ultraviolet radiation. Since 1978, almost all use of CFCs to propel aerosol products has been banned. As part of a study to examine the economic impact of regulating CFC emissions in nonaerosol applications, this Note assesses the implications of potential regulations for the CFC and precursor chemical producing industries.

The research was performed under contracts P.C. 68-01-3882 and 68-01-6111 for the U.S. Environmental Protection Agency. It is part of a larger program sponsored by EPA in conjunction with the Consumer Product Safety Commission and the Food and Drug Administration. Other studies are concerned with evaluating the biological and economic implications of ozone depletion. The present study specifically considers the industries that use and produce CFCs. This Note focuses particular attention on the manufacture of the CFCs themselves and their precursor chemicals. It should be of interest to readers in government and industry with a basic understanding of chemical production.

Three other Rand reports documenting results of this study are being produced. The first presents the detailed results of the study: Adele R. Palmer et al., *Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications*, R-2524-EPA. The second is based on a briefing to EPA summarizing the study results: Adele R. Palmer et al., *Economic Implications of Regulating Nonaerosol Chlorofluorocarbon Emissions: An Executive Briefing* (R-2575-EPA). The third provides greater detail on the analysis of flexible foam applications: William E. Mooz, *Flexible Urethane Foams and Chlorofluorocarbon Emissions* (N-1472-EPA).

SUMMARY

Recent studies have indicated that chlorofluorocarbons (CFCs) reach the stratosphere intact and contribute to depletion of the ozone layer. Most uses of CFCs as aerosol propellants were banned in the United States in 1978. This work is part of a study to examine the economic effects of regulations on nonaerosol CFC emissions. Specifically, it addresses the implications of limiting emissions on the CFC and precursor chemical production industries.

One purpose of this work is to update and extend the data base on CFC and precursor chemical production. This document presents estimates of the CFC production, sales, and aerosol and nonaerosol use for 1970 through 1977. A method based on the chemical equations for CFC production is used to estimate precursor chemical requirements for the same historical period. Recent production capacity data for the producers of CFCs and the precursor chemicals are also presented.

The second purpose of the work is to provide the framework for examining the implications of future CFC emissions reductions on the producing industries. Based on 1990 projections of CFC production, the techniques developed here are used to estimate 1990 CFC use and precursor chemical production requirements in the absence of policy action. Finally, to illustrate the applicability of the methods, two general policy strategies for limiting CFC emissions are considered. The effects on CFC and precursor chemical production of five policy designs within the two general policy strategies were examined. These five policy designs lead to cumulative (1980-1990) CFC emissions reductions of between about 15 and 30 percent.

The findings indicate that the aerosol ban has had a severe impact on production of CFCs used as propellants. Production of these CFCs (CFC-11, CFC-12, and CFC-114) is not expected to reach 1976 levels again until approximately 1990. The most stringent policy design considered for limiting nonaerosol emissions would lead to a 17 percent decline over the projected base case production of carbon

tetrachloride, one of the precursor chemicals. For the other precursor chemicals analyzed, the reduction would not exceed 7 percent.

This document contains information of general use for assessing the effects on production of any proposed level of CFC emissions reduction. A knowledge of the value of any one of three variables, CFC use, CFC production, or precursor chemical production, allows the estimation of the values for the other two variables.

ACKNOWLEDGMENTS

We are indebted to a large number of people who contributed heavily of their time, knowledge, and ideas during this study. We are particularly grateful to those in industry who reviewed the initial data and clarified many concepts.

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I. INTRODUCTION

In recent years, scientists have hypothesized that chlorofluorocarbons (CFCs) reach the stratosphere intact, and once there, contribute to depletion of the ozone layer. Although the problem is global, the United States has been the largest single user of CFCs. The Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) banned the use of CFCs as propellants in aerosol products in December 1978. In mid-1977, the EPA, together with the FDA and the Consumer Product Safety Commission, asked Rand to study the economic implications of regulatory strategies for limiting nonaerosol CFC emissions.

This document is part of a study of the economic effects of regulating CFC emissions. Its purpose is twofold. First, it updates and extends the data base on CFC and precursor chemical production, the production processes, and the producers. Second, it examines the implications of a mandatory control and economic incentives policy strategies for limiting emissions on future CFC and precursor chemical production. To accomplish the second objective, we developed techniques for relating precursor chemical production to CFC production, and CFC production to CFC use and emissions. Thus this document provides the framework for assessing the consequences of any future level of CFC emissions on the CFC and precursor chemical producing industries.

CFC uses are diverse and pervasive. It is a blowing agent for flexible foam used in bedding and carpet underlay, a blowing agent for foam used in food packaging applications, and an insulating medium in foam used to insulate buildings and refrigeration devices. CFC acts as a refrigerant in automotive air-conditioning units, home refrigerators and freezers, retail food refrigeration systems and commercial air-conditioning units, and as a solvent for metal cleaning and the defluxing of printed circuit boards. CFCs are used in a variety of other ways, including the liquid fast freezing of foods and the sterilization of hospital goods.

The CFC used in these numerous applications is manufactured by five chemical firms. The chemicals used as precursors to CFC manufacture are produced by many chemical firms. All producers of these chemicals would be affected by regulatory policies that limit non-aerosol CFC emissions. Limiting emissions reduces use which in turn reduces production of the CFCs and the precursor chemicals used in their manufacture.

Although approximately a dozen CFCs are manufactured presently in the United States, only three, CFC-11, CFC-12, and CFC-113, are of primary concern, both because they are fully halogenated,[1] and because they are widely used. CFC-22, which is also widely used, is not as hazardous to the ozone layer as those CFCs listed above. Analysis of CFC-22 is included here because it is a potential substitute for the more hazardous CFCs in refrigeration applications. Another chlorofluorocarbon, CFC-114, also fully halogenated, is used in relatively small quantities in a limited number of applications. CFC-502 and CFC-500, which are combinations of other CFCs in various proportions, are, like CFC-114, not widely used.

This study provides estimates of production of the CFCs and the most important precursor chemicals as well as estimates of total CFC use from 1970 to 1977. Projections of annual production of the CFCs and precursor chemicals extend through 1990. These projections form a base case production profile in the absence of regulation. The implications on CFC and precursor chemical production of limiting CFC emissions and use under two general policy strategies which include five policy designs are evaluated. These five policy designs result in rather modest reductions in CFC emissions, between about 15 and 30 percent for the period 1980-1990.

One important finding of this study is that the ban on CFCs for use as propellants has been very significant in decreasing CFC production requirements. For those CFCs that were heavily used in aerosols (CFC-11, CFC-12, and CFC-114), production will not again reach 1976 levels until the end of the decade. Alternatively, production of CFC-113 and CFC-22, neither of which was used as a propellant, has continued to increase.

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[1] A CFC that is fully halogenated contains no hydrogen.

Limiting CFC emissions to the extent considered here will have a much smaller effect on CFC and precursor chemical production than has the aerosol ban. The precursor chemical that would be most affected by these regulatory policies is carbon tetrachloride, used to manufacture CFC-11 and CFC-12. Even in this case, however, total production would decline, at most, by 17 percent over projected base case levels. The other precursor chemicals, since a smaller portion of their production is devoted to CFC manufacture, would decrease by less than 6 percent from the base case projections.

Section II of this document presents the chemical equations for the production of the CFCs. The precursor chemicals that are most dependent on continuing CFC production are identified.

Historical production of the CFCs from 1970 to 1977 is given in Section III. These data, together with the chemical equations in Section II, are used to develop estimates of the historical precursor chemical production requirements for CFC manufacture. The techniques for relating a particular level of CFC production to a particular level of precursor chemical production are useful in a more general sense. Production of a precursor chemical can be determined by multiplying production of any CFC for any year by the appropriate "factor" (given in Appendix A) for the individual precursor chemical.

In Section IV, we discuss the destinations of the various CFCs from the time they are produced until the time they are used. A model for estimating CFC end use from CFC production is developed using the historical production figures of Section III.

In Section V, the producers of the CFCs and precursor chemicals are identified. We also assess the dependence of each producer on CFC manufacture for the historical period based on plant capacity and information obtained from industry sources.

Base case projections of 1990 CFC production, derived from industry-supplied data, are given in Section VI. The techniques developed in Section IV are used to estimate 1990 CFC use. These use data are then compared with 1990 projections of CFC use developed in this study for most major and some minor CFC applications. The CFC production data are also used, together with the methods of

Section III, to derive base case estimates of 1990 precursor chemical production. Reductions in CFC use resulting from five policy designs for reducing 1990 CFC emissions are presented. Using the techniques developed in Sections III and IV, these reductions in use are translated into reductions in 1990 CFC and precursor chemical production.

In Section VII, we present the general conclusions of this study. In addition, we stress the wider applicability of the methods developed here. If a future value for any of the three variables (CFC use, CFC production, or precursor chemical production) is available, values for each of the other two variables can be estimated. The data and methods of this document serve as a framework for assessing the effects of potential future CFC emissions limitations on the producing industries.

II. CFC PRODUCTION PROCESSES

The chemicals considered in this study are CFC-11, CFC-12, CFC-113, CFC-114, and CFC-22. Because they contain both chlorine and fluorine, they are referred to as chlorofluorocarbons (CFC). They are highly unreactive and may not decompose prior to entering the stratosphere. CFC-22, which contains a hydrogen atom, is hypothesized to be more susceptible to decomposition. Even so, it is important to consider CFC-22, both because it may reach the stratosphere intact, and because it is often mentioned as a potential substitute for the fully halogenated CFCs in some applications.

Five U.S. companies currently manufacture CFCs: E. I. DuPont de Nemours (DuPont), Allied Chemical Corporation (Allied), Kaiser Aluminum and Chemical Corporation (Kaiser), Pennwalt Corporation (Pennwalt), and Racon, Inc. (Racon), now part of Essex Chemical Company. Another company, Union Carbide Corporation, recently discontinued production of CFCs.[1] All five producers manufacture CFC-11, CFC-12, and CFC-22, while only DuPont and Allied produce CFC-113 and CFC-114.

As far as can be determined, similar production processes are used by all the manufacturers.[2] The pairs CFC-11/CFC-12 and CFC-113/CFC-114 are coproduced; plants designed for the production of one pair cannot readily be converted to production of the other pair.[3] This section describes the chemical processes for CFC manufacture. Some chemicals are highly dependent on CFC manufacture, either because a large percentage of the total production is used for CFC manufacture, or because they could not readily find use in other applications. These precursor chemicals are identified as each CFC production process is considered.

---

[1] Union Carbide has sold its production equipment to IPI of Wichita, Kansas, which may produce CFC-11, CFC-12, and CFC-22 in the future.

[2] Although the same chemical equations apply for CFC manufacture, the process conditions may vary from producer to producer.

[3] Section V gives a brief discussion of plant conversion.

CFC-11/CFC-12

Two processes, commonly called the liquid phase process and the vapor phase process, may be used to coproduce CFC-11 and CFC-12. Both processes use the same chemical inputs, carbon tetrachloride (CCl_4) and anhydrous hydrogen fluoride (HF), and both yield CFC-11 and CFC-12 as well as byproduct hydrochloric acid (HCl). The main differences between the two manufacturing methods are that the vapor phase process uses higher temperatures in general, and is subject to over-fluorination yielding CFC-13.[1] According to knowledgeable industry sources, the HCl produced as a byproduct in both processes is an extremely important factor in the economics of production. Markets for the HCl are dynamic, and both the quality of the byproduct HCl and CFC plant location can influence the salability of this chemical.

Another important economic consideration to the producer is the precursor chemical requirement for CFC production. Industry sources estimate yields from the liquid and vapor phase processes as 98 and 97 percent respectively, which implies that the material costs for the two processes are almost the same. Reference 1 asserts that material costs represent more than 70 percent of the production cost in a CFC plant operating at full capacity.

CFC-11 and CFC-12 are produced according to the following chemical equations:

$$CCl_4 + HF \rightarrow HCl + \underset{\text{(CFC-11)}}{CCl_3F} \qquad \text{(II-1)}$$

$$CCl_4 + 2HF \rightarrow 2HCl + \underset{\text{(CFC-12)}}{CCl_2F_2} \qquad \text{(II-2)}$$

Nearly all of the CCl_4 and almost half of the HF[2] produced domestically are used in CFC manufacture. According to Reference 1 and

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[1] Industry individuals contend that there is very little market for this CFC.

[2] A large amount of HF is also used in the aluminum industry.

industry sources, CCl_4 can be produced in three ways: using propylene (C_3H_6) and chlorine (Cl_2) with coproduction of perchloroethylene (C_2Cl_4);[1] using carbon disulfide (CS_2) and chlorine; or using methane (CH_4) with chlorine.[2] The three production processes can be described as follows:[3]

$$aC_3H_6 + (7a-2b)\ Cl_2 \rightarrow (a-2b)\ CCl_4 + (a+b)\ C_2Cl_4 + 6aHCl \qquad \text{(II-3)}$$

$$CS_2 + 2Cl_2 \rightarrow CCl_4 + 2S \qquad \text{(II-4)}$$

$$CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl \qquad \text{(II-5)}$$

C_3H_6, CH_4, many of the chlorocarbons, and CH_3OH are common raw materials in high demand, and therefore they could probably find use elsewhere if CFC production were in some way limited. The precursor to CCl_4 production that could be affected by a change in CCl_4 demand is CS_2. Cl_2 would also be affected, but to a lesser extent.

---

[1] Chemicals other than propylene, including hydrocarbons and chlorocarbons, can be used to produce CCl_4. Industry sources indicate that chlorocarbon byproducts obtained from other processes such as vinyl chloride and propylene oxide production are frequently used as feed.

[2] Some CCl_4 is obtained using methanol (CH_3OH) or methylchloride (CH_3Cl) in the coproduction of methylene chloride (CH_2Cl_2) and chloroform ($CHCl_3$). For simplification, since the starting material can be traced to CH_4, the process will be considered as described above.

[3] In Equation II-3, the small letters, a and b, are meant to indicate that the process can be varied to produce a different mix of CCl_4 and C_2Cl_4 depending on the proportions of the input chemicals and reactor conditions. As will be seen later, C_2Cl_4 is used in the production of CFC-113/CFC-114. This method of producing C_2Cl_4 and CCl_4 is one of many examples which illustrate the interrelationships in the chemicals industry. If production of a given chemical were discontinued, all other downstream chemicals and possibly some upstream chemicals would also be affected.

The other input to CFC-11/CFC-12 manufacture, HF, is produced using fluorspar (CaF_2) and sulfuric acid (H_2SO_4) in the following way:

$$CaF_2 + H_2SO_4 \rightarrow 2HF + CaSO_4 \qquad \text{(II-6)}$$

Only a very small percentage of total H_2SO_4 goes toward CFC manufacture. Although about one-third of the fluorspar consumed in the United States is so employed, much of it is imported.[1] Neither H_2SO_4 or CaF_2 will be considered further here, H_2SO_4 because of its minor use in CFC manufacture, and CaF_2 because much of it is mined outside the United States. Both precursors, however, would be affected by a change in CFC production.

CFC-22

This CFC is produced using chloroform ($CHCl_3$) and HF in the following manner:[2]

$$CHCl_3 + 2HF \rightarrow 2HCl + \underset{\text{(CFC-22)}}{CHClF_2} \qquad \text{(II-7)}$$

In this case, as with CFC-11/CFC-12, the marketability of the byproduct HCl can have a significant effect on the manufacturing economics. Equation II-7 illustrates that CFC-22 production requires HF, as does CFC-11/CFC-12 production, but requires a different chlorocarbon. In fact, some plants are designed to manufacture either CFC-11/CFC-12 or CFC-22 by changing the chlorocarbon feed.[3]

Since much of the $CHCl_3$ produced goes toward CFC manufacture, this chemical is highly dependent on continuing CFC production. The $CHCl_3$ is made from either CH_4 or methanol and Cl_2 as follows:

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[1] There are, however, fluorspar mines within the United States owned by Allied and Pennwalt.

[2] A small amount of coproduct CFC-23 is also produced in this process.

[3] Facilities of this type are referred to as campaign plants.

$$CH_4 + 3Cl_2 \rightarrow CHCl_3 + 3HCl \qquad \text{(II-8)}$$

$$CH_3OH + 2CL_2 \rightarrow CHCl_3 + HCl + H_2O \qquad \text{(II-9)}$$

HF manufacture was discussed previously, and the relevance of CH_4, CH_3OH and Cl_2 has already been addressed.

CFC-113/114

There is less available information on the production of these two CFCs than for CFC-11 and CFC-12. There are only two producers, and frequently the data are considered proprietary.[1] CFC-113 and CFC-114 are manufactured using perchloroethylene (C_2Cl_4), HF, and Cl_2 according to the chemical equations:

$$C_2Cl_4 + 3HF + Cl_2 \rightarrow \underset{\text{(CFC-113)}}{C_2Cl_3F_3} + 3HCl \qquad \text{(II-10)}$$

$$C_2Cl_4 + 4HF + Cl_2 \rightarrow \underset{\text{(CFC-114)}}{C_2Cl_2F_4} + 4HCl \qquad \text{(II-11)}$$

Less than 20 percent of total U. S. perchloroethylene output is used in the manufacture of these CFCs. However, since much of it is coproduced with CCl_4 as shown in Equation II-3, the implications of limiting its production could be significant. Most of the remaining C_2Cl_4 is produced using ethylene (C_2H_4) and Cl_2 to produce C_2Cl_4 and trichloroethylene (C_2HCl_3) according to Equation II-12.[2]

$$2C_2H_4 + 7\ Cl_2 \rightarrow C_2HCl_3 + C_2Cl_4 + 7HCl \qquad \text{(II-12)}$$

---

[1] One of the CFC-113/CFC-114 producers, DuPont, employs a vapor phase catalysis, while the other, Allied, utilizes a liquid phase catalysis.

[2] The disposal of HCl produced in the process described by Equation II-12 can be handled in a number of ways, according to industry sources. Although we do not know the manner for dealing with the HCl, we rely on the industry assessment. Thus the HCl generated from the process given in Equation II-12 will not be considered in the later analysis.

C_2H_4, a hydrocarbon in high demand, could readily find other uses if C_2Cl_4 production were curtailed. The input Cl_2 has already been discussed.[1]

PRECURSOR CHEMICALS

The production of each of the five CFCs is a final step in a complex series of chemical reactions. The intermediate precursors, those used directly in CFC manufacture, are, in turn, produced using preliminary precursors. Table I-1 summarizes the preliminary and intermediate precursor chemicals that would be significantly affected by a change in CFC production levels.

Table II-1

PRECURSOR CHEMICALS FOR CFC PRODUCTION

CFC	Intermediate Precursor	Preliminary Precursor
CFC-11/CFC-12	CCl_4	Cl_2
	HF	
CFC-22	$CHCL_3$	Cl_2
	HF	
CFC-113/CFC-114	C_2Cl_4	Cl_2, CS_2
	HF	
	Cl_2	

[1] Reference 2 states that 3 percent of the C_2Cl_4 is produced using C_2H_2. This process will not be considered here since the amount produced is negligible.

III. HISTORICAL PRODUCTION OF CFCs AND PRECURSOR CHEMICALS

In the last section, the processes for manufacturing the CFCs were described, and the precursor chemicals used in these processes were identified. Potential regulatory strategies for limiting CFC emissions would lead to lower CFC production levels and, consequently lower precursor chemical production requirements. The CFC aerosol propellant ban has had major effects on production of some CFCs and precursor chemicals. In light of future potential CFC emissions limitations, it is thus useful to examine the historical trends. In this section we present historical CFC production and sales data. These data, together with historical precursor chemical production figures, permit estimates of the portion of each precursor chemical used for CFC manufacture.

CFC-11/CFC-12

The historical production data on CFC-11/CFC-12 are quite extensive and show good general agreement from source to source. Table III-1 shows production for 1970 to 1977 taken from Reference 3. Historical sales, which differ from production for a number of reasons,[1] are also shown in Table III-1.

The values of Table III-1 illustrate that CFC-11 and CFC-12 production increased through 1974 and exhibited an abrupt decline in 1975. Prices of all chemicals increased markedly in 1974[2] and this may have acted to reduce demand for CFCs. In addition, the fear of shortages in 1974 resulted in large inventories in the supply chain. One further event which almost surely contributed to the decrease in production was the initiation of discussions concerning proposed controls over CFC propellants.

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[1] The reasons for this difference are discussed in Section IV.

[2] This was, in part, a result of the increase in petroleum prices which occurred at that time.

Table III-1

CFC-11/CFC-12 PRODUCTION AND SALES--1970-1977

(millions of pounds)

Year	CFC-11			CFC-12			Total Production
	Production[a]	(Percent of Total)	Sales[a]	Production[a]	(Percent of Total)	Sales[a]	
1970	244	(39)	237	375	(61)	356	619
1971	258	(40)	237	390	(60)	372	648
1972	300	(41)	286	439	(59)	419	739
1973	334	(41)	329	489	(59)	464	823
1974	341	(41)	321	487	(59)	449	828
1975	270	(41)	254	393	(59)	375	663
1976	256	(39)	239	393	(61)	371	649
1977	213	(37)	197	358	(63)	340	571

[a]Figures were taken from Reference 3.

CFC-22

Historical CFC-22 production and sales as given in various references is shown in Table III-2. Production of CFC-22, like that of CFC-11 and CFC-12, shows a decline from 1974 to 1975. However, unlike CFC-11 and CFC-12 production, CFC-22 production increased dramatically from 1975 to 1977. We note that CFC-22 sales as a fraction of production averaged about 72 percent for the period; the value for CFC-11/CFC-12 sales was approximately 95 percent. The reason for this difference is discussed in Sections IV and V.

Table III-2

CFC-22 PRODUCTION AND SALES--1970-1977
(millions of pounds)

Year	Production	Sales[a]
1970	100[b]	73
1971	112[b]	80
1972	123[b]	80
1973	136[b]	97
1974	141[b]	112
1975	132[a]	94
1976	170[a]	126
1977	179[a]	129

[a]Values were taken from Reference 3.
[b]Values were taken from Reference 1.

Table III-3

CFC-113/CFC-114 PRODUCTION AND SALES--1970-1977

(millions of pounds)

	Reference 1		Estimates				
			CFC-113		CFC-114		
Year	Production CFC-113	CFC-114	Production	Sales	Production	Sales	Total Production
1970	36	22	43	41	35	29	78
1971	43	23	44	42	39	33	83
1972	50	25	51	49	43	37	94
1973	59	26	68	64	43	37	111
1974	64	27	72	69	44	38	116
1975	--	--	65	62	39	33	104
1976	--	--	72	69	37	31	109
1977	--	--	84	80	25	19	109

CFC-113/CFC-114

CFC-113/CFC-114 production is not as readily available as for the other CFCs. Reference 3 has a category entitled "all other fluorinated hydrocarbons," which presumably includes, but does not specify individually, CFC-113 and CFC-114 production and sales. Table III-3 shows CFC-113 and CFC-114 production and sales from Reference 1 and as estimated by Rand. For purposes of this study, the Rand estimates will be adopted since they derived from recent conversations with industry sources and therefore should be more reliable.

Table III-3 also shows the familiar decline in production from 1974 to 1975 for both CFC-113 and CFC-114. One apparent difference between CFC-113 and CFC-114 is that CFC-113 shows an increase in sales from 1975 to 1977 while CFC-114 shows a decrease. CFC-113 and CFC-22 are the only two CFCs which do exhibit this behavior. The reason this trend might be expected for both CFCs is that only a miniscule amount of each has been used to charge aerosol products,[1] and production would therefore not have been significantly affected by anticipation of the propellant ban.

PRECURSOR CHEMICALS

The precursor chemicals that are highly dependent on CFC manufacture were identified in Section II as CCl_4, HF, $CHCl_3$, C_2Cl_4, CS_2, and Cl_2. The chemical equations for CFC manufacture together with process efficiencies provide the basis for estimating precursor chemical requirements for CFC production.

Appendix A presents the detailed procedure for calculating precursor chemical requirements. Using the chemical equations and industry-supplied data on individual process efficiencies, factors

[1] End uses for each CFC are discussed more fully in Section IV.

representing the fraction of each precursor chemical necessary for a unit of CFC production were developed. These factors multiplied by a specific level of CFC production give the corresponding precursor chemical requirements.

To illustrate this procedure, Appendix B presents estimates of the precursor chemical requirements for historical CFC production. The estimates are compared with information contained in available data sources. Total production of the precursor chemicals is also given to determine the portion of each precursor chemical devoted historically to CFC manufacture.

Table III-4 summarizes the estimates of each precursor chemical required for historical CFC production and also gives the quantity of HCl produced as a byproduct in CFC and some precursor chemical production processes. The percent of total production of each precursor chemical which went toward CFC manufacture during this time are provided

Table III-4

PRECURSOR AND BYPRODUCT CHEMICALS
FOR CFC MANUFACTURE--1970-1977

(millions of pounds)

Year	CCl_4	HF	$CHCl_3$	C_2Cl_4	CS_2	Cl_2	Byproduct HCl
1970	766	245	145	75	151	1438	846
1971	801	260	162	79	158	1520	897
1972	913	291	178	90	181	1722	1014
1973	1017	325	197	106	201	1924	1132
1974	1022	331	204	110	202	1945	1146
1975	819	279	191	99	162	1617	957
1976	803	296	247	103	159	1690	1054
1977	708	281	260	102	140	1572	951

SOURCE: Tables B-1 through B-11.

in Table III-5. A significant portion of CCl_4, HF, and $CHCl_3$ production demand was devoted to CFC manufacture.

The techniques developed in this section are intended to illustrate an approach for determining the precursor chemical requirements for CFC manufacture. With this framework, given CFC production for any future year, a simple calculation will yield the corresponding amounts of precursor chemicals needed.

Table III-5

PERCENTAGE OF PRECURSOR CHEMICAL PRODUCTION DEVOTED TO CFC MANUFACTURE--1970-1977

Year	CCl_4	HF[a]	$CHCl_3$	C_2Cl_4	CS_2[b]	Cl_2[c]
1970	76	--	60	10	--	--
1971	79	--	70	11	--	--
1972	92	--	76	12	23	--
1973	97	44	78	15	--	9
1974	88	41	68	15	26	9
1975	90	--	73	14	--	--
1976	94	46	85	15	--	--
1977	88	--	86	17	--	--

[a]Total production for HF is unavailable for the historical period. Reference 4 gives 1973 total production as 733 million pounds, and Reference 5 gives 1974 production as 799 million pounds. Industry sources have indicated that in 1976, 46 percent of total HF went toward CFC manufacture.

[b]References 6 and 5 give total 1972 and 1974 CS_2 production as 775 and 772 million pounds respectively.

[c]References 6 and 5 give total Cl_2 production figures for 1973 and 1974 of 20,804 and 21,236 million pounds respectively.

IV. HISTORICAL CFC END USE

In the previous two sections, a method for estimating precursor chemical production requirements from CFC production data was developed. To evaluate the implications of reducing CFC emissions, we also need techniques for relating CFC emissions to CFC use which can ultimately be translated into CFC and precursor chemical production. Reference 8 examines 1976 CFC use and emissions in detail. These data can be used to relate CFC emissions to CFC use in the historical case.

In this section, we develop a method for translating historical CFC production into historical CFC end use. Estimates of historical CFC nonaerosol use, together with the data of Reference 8, show the method to be a reasonable one for translating a reduction in CFC nonaerosol use directly into a reduction in CFC production requirements.

NON-USE EMISSIONS

Section III implicitly assumed that emissions during the CFC production process occur prior to the reporting of production figures. Reference 4 cites emissions estimates from production, storage, and transport as 1 to 2 percent of total production. More recent estimates from industry sources of 2 percent from production and a further 2 percent from post-production activities (but prior to use) are adopted here.[1]

It will be assumed that the reported historical values for CFC production already reflect the 2 percent production emissions loss.[2]

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[1] Although one producer reports 1 percent losses, the 2 percent loss is used as an industry average.

[2] Those emissions which are classified as "production emissions" probably refer to losses of CFC which occur during the manufacturing process. It seems reasonable to assume that the reported production figures reflect the amount of CFC remaining after these losses have taken place. Many sources subtract production emissions from the production figures; however, in this study, values for production will be used with the assumption that these losses have already been taken into account. Thus, production refers to the amount of CFC present in the storage tanks of the producers.

The additional 2 percent loss from such activities as distribution, storage, packaging, and transport, remains to be considered.

In many cases, the CFC user does not purchase directly from the producer. The producer may sell the CFC to a distributor who will frequently repackage it before delivery to the user. Many large users also repackage CFC prior to use. Unfortunately, data specifying the losses during these different practices do not exist. Thus it will be assumed here that the sales figures refer to producer sales, and that the storage, packaging, and transport emissions occur after these sales take place.[1] Undoubtedly, some of these emissions occur before and some after sales; however, since the sales and production values do not differ significantly, the error introduced by assuming that emissions occur following sales is insignificant.

One of the purposes of this study is to estimate and examine the economic effects of reducing the emissions from nonaerosol CFC uses. Even though the emissions described above occur prior to use, they are nevertheless an emissions source of CFC. In our opinion, current emissions from production, storage, packaging and transport are probably as low as can reasonably be expected at *current CFC prices.*[2] Because production emissions occur prior to producer sales, the producer has an economic incentive to be conservative with the CFC. The same situation applies to emissions from packaging by distributors or users since all parties involved are concerned with maximizing the amount of CFC ultimately available for sale or use. It is therefore

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[1] Reference 3, from which the sales figures for CFC-11, CFC-12, and CFC-22 were taken, cites sales as those by the original manufacturer.

[2] The energy crisis provides a useful analogy. As energy prices increased, conservation techniques and practices, which may have once seemed extreme, became commonplace. If CFC prices were to increase, industry would almost certainly find ways to reduce these emissions further. The technology for achieving this reduction is obviously currently available since emissions from production of chlorocarbons are negligible, as discussed in Appendix A.

probably reasonable to assume that unless a program of specific regulation on CFC output were enacted, there would be no reduction in these emissions.[1]

INTERMEDIATE/IN-HOUSE USE

The difference between the values given in Section III for CFC production and sales can be attributed to intermediate and/or in-house use[2] of the CFC by the manufacturers. One example of intermediate use by producers is the use of CFC-114 to produce CFC-115 which is combined with CFC-22 to produce CFC-502, a refrigerant.[3] There are numerous other intermediate uses for each of the CFCs where emissions are negligible. We accept that most of the difference between the production and sales figures of Section III is due to these consumptive uses of CFC that are not directly categorized as emissions.

Reference 9 details many small in-house uses of the CFCs, the most common of which are refrigerants and solvents. This reference includes CFC-113 in-house use in the sales figures. Consequently, for this CFC, it will be assumed that in-house uses do not account for the difference between production and sales. For the other CFCs, the in-house use, together with intermediate use, accounts for the total difference between the sales and production figures.

INVENTORIES

The CFCs are inventoried in various places between production and use. They may be stored by the producer prior to delivery, quantities may be held at distribution or packaging points, and some may be in transit in tank cars, cylinders, or drums.

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[1] Industry sources indicate that there is ongoing research intended to reduce these emissions so that yields can be increased and costs decreased.

[2] Intermediate use is defined here as use of the CFC for direct conversion into another chemical compound. In-house use is defined as use of the CFC itself.

[3] CFC-502 is 48.8 percent CFC-22 and 51.2 percent CFC-115 by weight.

Industry sources indicate that 15 to 30 days elapse between CFC sales and delivery for use.[1] It therefore seems reasonable to assume that about 6 percent of each year's sales will not be available for emission until the following year.[2] To a large extent, inventories available from a previous year will cancel those taken out in a current year. For this reason, inventories are not considered further in this analysis.

EXPORTS

We have been told by knowledgeable sources that CFC imports have historically been negligible. However, exports evidently account for a more significant portion of sales. Although there is no information on the amount of each CFC exported, there are some data on total CFC exports.

Reference 4 indicates that 7 percent of the CFCs produced in 1973 fall into a category entitled "exports and other." In Reference 5, exports are listed as having accounted for 4 percent of 1973 production. Knowledgeable sources claim that CFC-113 annual exports are 4 to 6 percent of sales. Given these data, it will be assumed that annual exports were historically about 5 percent of sales.[3]

AEROSOL USE

Each of the CFCs has more than one end use although, generally, one primary application consumes a very large portion of use in each case. Since we are concerned only with the nonaerosol uses and emissions of the CFCs in this study, we need to estimate the magnitude of historical use in aerosols, since the propellant ban will prevent CFC from being used for this purpose in the future.[4] Three of the CFCs

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[1] One industry source states that this time is 24 hours for bulk sales.

[2] It would serve no purpose to detail inventories on a more frequent basis than annually.

[3] In the future, this assumption may not be valid.

[4] Anticipation of the aerosol ban led to many changes in the CFC and precursor chemicals industries, which are discussed in more detail in Section V.

under consideration in this study, CFC-11, CFC-12, and CFC-114 were used historically as aerosol propellants. There is no indication that significant amounts of either CFC-22 or CFC-113 were used in this way.[1]

Table IV-1 shows our estimates of 1976 production, intermediate use, sales, emissions, exports, aerosol use, and nonaerosol use for each CFC. Nonaerosol end use is the difference between the sales figures and emissions, exports, and aerosol use. Appendix C presents complete historical (1970-1977) estimates for the CFC apportionment, and discusses the values for aerosol use in detail. The method for allocating CFC to the various destinations of Table IV-1 is described mathematically in Appendix D.

NONAEROSOL USE

Reference 8 specifically addresses CFC nonaerosol use in all major and some minor applications. Estimates of current and future use for each CFC are presented. In most cases, 1976 was chosen as the most recent historical point for which data were available. Comparison of these data with the values for nonaerosol use in Table IV-1 provides an indication of the validity of the method of accounting for the CFC after it is produced.

Table IV-2 presents the amount of each CFC that went toward selected end use categories in 1976 as taken from Reference 8. These include various foam and refrigeration applications as well as solvents, LFF (Liquid Fast Freezing), and sterilants. There are various other uses for the CFCs that have not been included in Table IV-2. We refer to the categories of CFC use included in Table IV-2 as analyzed applications while all other CFC uses are unanalyzed applications.

The values of Table IV-2 for CFC-11 indicate that the major amount of this CFC was consumed in the manufacture of foams in 1976. Smaller quantities were used in refrigeration and miscellaneous applications in 1976. According to Reference 9, CFC-11 was also used in industrial refrigeration applications which could account for the balance of the 19 million pounds.

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[1] Some CFC-113 is packaged in aerosols and used for cleaning purposes. In these cases, however, the CFC-113 is not used as the propellant. In any event, this application accounts for a negligible percentage of total CFC-113 use.

Table IV-1

CFC APPORTIONMENT--1976

(millions of pounds)

CFC	Production	Intermediate Use	Sales	Emissions[a]	Exports[b]	Aerosol Use[c]	Nonaerosol Use[d]
CFC-11	256	17	239	5	12	123	99
CFC-12	393	22	371	7	19	156	189
CFC-22	170	44	126	3	6	--	117
CFC-113[e]	72	--	--	--	--	--	69
CFC-114	37	6	31	1	2	26	2

[a]Emissions cited in the table are those resulting from storage, packaging, and transport and do not include CFC emitted during the production process.

[b]Estimated at 5 percent of sales.

[c]Estimated from available sources and industry-supplied data. See Appendix C for details.

[d]Sales minus emissions minus exports minus aerosol use.

[e]Reference 8 describes CFC-113 in detail.

Table IV-2

ESTIMATED CFC NONAEROSOL END USE-1976

(millions of pounds)

Analyzed Applications	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114
Flexible Foam	34				--
Solvents[a]	--	--	--	69	--
Rigid Foams:					
Urethane	35	2	--	--	1
Nonurethane	2	21	--	--	
Mobile Air Conditioning	--	90	--	--	
Other Refrigeration:					
Chillers	8	5	3	--	1
Home Refrigerators and Freezers	--	6	--	--	
Retail Food	--	11	1	--	
Miscellaneous:					
LFF	--	6	--	--	
Sterilants	--	13	--	--	
Other	1	3	--	--	
TOTAL	80	157	4	69	2

NOTE: Uses reported for individual applications exclude: 5 million pounds each of CFC-22 and CFC-115 used to form CFC-502; less than 1 million pounds each of CFC-12 and CFC-152a used to form CFC-500.

[a]Refrigeration and other relatively small miscellaneous uses of CFC-113 are included in the solvents data.

Although most of the CFC-12 is used in refrigeration applications, it is also used in numerous other applications. Comparison of the CFC-12 values of Tables IV-1 and IV-2 implies that more than 30 million pounds were used in unanalyzed applications in 1976. Indeed, Reference 9 indicates that a large amount of CFC-12 was used in industrial, transportation, and cold storage refrigeration.

The values of Table IV-2 show that only a small amount of CFC-22 was used in the analyzed applications. Part of the balance was probably consumed in other refrigeration (primarily air conditioning) applications. Industry sources have stated that a large portion

of the CFC-22 is used to produce tetrofluoroethylene (TFE) from which teflon is manufactured. Although the large intermediate use of CFC-22 may account for this use, it could be that a large amount of CFC-22 is also sold for TFE production.

In the case of CFC-113, the solvent application accounts for 96.3 percent of the CFC-113 available for use. Although possibly 2 million pounds was used to manufacture foam and in refrigeration applications, all CFC-113 use is shown for solvents.

Table IV-1 shows that about 2 million pounds of CFC-114 were available for nonaerosol end use. The values of Table IV-2 agree well with this estimate, allocating about 1 million pounds each to foam manufacture and use as a refrigerant in chillers.

The method for relating CFC production to CFC end use seems to provide reasonable values for 1976 in light of the data of References 8 and 9. There remains, however, some degree of uncertainty in the estimates of the parameters. For example, although industry sources cannot specify export levels for each CFC, they have indicated that the estimates derived here may be slightly high. However, without more detailed information on the magnitude of the exports, the estimates must suffice.

V. CFC AND PRECURSOR CHEMICAL PRODUCERS

An understanding of CFC and precursor chemical market features will provide insight into the possible behavior of the producers under the conditions that a given future policy might imply. The ban on CFC use as propellants had an influence on the CFC and precursor chemical markets even before it was fully effective. The responses of the producers to this impending limitation may provide an indication of future behavior if regulations regarding nonaerosol CFC emissions were enacted. In this section, both historical and current market features are discussed and some implications of reduced production requirements are examined.

CFC PRODUCERS

DuPont is the largest U. S. producer with an annual capacity of more than half of the entire industry. Allied is the second largest U. S. producer. These two producers manufacture all five CFCs. Only CFC-11, CFC-12, and CFC-22 are manufactured by the other three producers: Kaiser, Pennwalt, and Racon.

Annual Capacity

An important factor in a competitive market is the relative market share held by each of the participants. Unfortunately, for obvious reasons, production and sales data for each of the individual CFC producers are not publicly available; however, total industry data as given in Section II do exist for each CFC. These data, together with company specific production capacity, provide the basis for deriving estimates of each firm's portion of total sales.

Various references list the capacities of each producer for particular years. As will be seen shortly, a number of changes have taken place since the information contained within these references was obtained. Table V-1 gives the capacities specified by two references, and also the capacities which we believe are currently more accurate.

Table V-1

CFC CAPACITY BY U.S. PRODUCERS

(millions of pounds)

Firm	Reference 4 1973		Reference 1 1976		Estimated 1978	
	Capacity	Percent[a] of Total	Capacity	Percent[a] of Total	Capacity	Percent of Total
Allied	310	25.9	319	21.6	240	22.6
DuPont	500	41.8	695	48.4	600	56.6
Kaiser	50	4.2	80	5.6	80	7.6
Pennwalt	115	9.6	115	8.0	90	8.5
Racon	20	1.7	35	2.4	50	4.7
Union Carbide	200	16.7	200	13.9	--	--
TOTAL	1195	100.0	1435	100.0	1060	100.0

[a]The values may not add to 100 percent due to rounding.

The differences between the estimated 1976 capacities and those of the other references may be attributable to plant closings. For example, Union Carbide recently discontinued direct CFC production, while DuPont, Allied, and Pennwalt closed entire facilities or portions of them. The closing of these plants undoubtedly resulted from anticipation of the aerosol ban, and should have involved primarily CFC-11/CFC-12 plants.

Capacity for CFC-114, which was also used in aerosols, would not be affected since the amount produced is relatively small and CFC-114 plants are also used to produce CFC-113.[1] It is true, however, that within the last few years, two CFC-113/CFC-114 plants were closed by current producers, as old units were phased out to bring new units onstream. One notable event for which there is no obvious explanation is that several years ago, Pennwalt and Union Carbide joined the CFC-113 market, but left shortly thereafter. It may well be that the CFC-113 demand could not support plants owned by four producers.

Table V-1 shows the shift which occurred in the capacity share held by each producer in the time period reflected by the values of Reference 4 and those estimated for 1978. Racon, Kaiser, and DuPont increased their capacity shares significantly, while Pennwalt's and Allied's shares declined. The increase in share experienced by some of the producers was governed by Union Carbide's discontinuing production. It is clear, however, that the share held by Union Carbide was not subsequently spread evenly among the other five producers.

Given the producers' total capacity, we now want to consider the capacity for each CFC held by each producer. It is estimated that DuPont holds about two-thirds and Allied one-third of total CFC-113/CFC-114 capacity estimated at 150 million pounds. Reference 5 gives the capacity of DuPont's single CFC-22 production facility as 120 million pounds; that estimate will be adopted here. The balance of

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[1] Although CFC-114 is largely used in aerosols, CFC-113 production currently represents about 76 percent of total CFC-113/CFC-114 production. Thus, CFC-113/CFC-114 plant closings would be unlikely to occur based on less CFC-114 production. In fact, in 1977 only 14 million pounds of CFC-114 went toward aerosol uses.

DuPont's capacity, 380 million pounds, can be allocated to CFC-11 and CFC-12 according to the 1977 relative production of each. After accounting for CFC-113/CFC-114 capacity, Allied has 190 million pounds of capacity remaining for CFC-11, CFC-12, and CFC-22. In 1977, CFC-22 production represented about 24 percent of combined CFC-11, CFC-12, and CFC-22 production. If this percentage is applied to Allied's capacity for these three CFCs, it is estimated that Allied's CFC-22 capacity is 45 million pounds. CFC-11 and CFC-12 capacities are then 54 and 91 million pounds respectively.

It will be assumed that this same reasoning applies to Pennwalt and Kaiser, who each have one plant which produces the three CFCs. Racon has one CFC-11/CFC-12 plant, and two plants devoted entirely to CFC-22 production. Thus, CFC-22 may account for as much as half of Racon's production, and it will be assumed that this is the case.

Given these assumptions, Table V-2 presents the estimated capacity and percent of total capacity for each CFC held by the individual producers. Appendix E presents historical CFC capacity as well as a method of apportioning capacity to each CFC.

Table V-2

1977 CAPACITY APPORTIONMENT

(millions of pounds)

	Annual Capacity (Percent of Total Capacity)					
Producer	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114	Total
Allied	54 (22)	91 (21)	45 (20)	38 (33)	12 (33)	240
DuPont	142 (57)	238 (56)	120 (52)	77 (67)	23 (67)	600
Kaiser	23 (9)	38 (9)	19 (8)	--	--	80
Pennwalt	26 (10)	43 (10)	21 (9)	--	--	90
Racon	6 (2)	19 (4)	25 (11)	--	--	50
TOTAL	251 (100)	429 (100)	230 (100)	115 (100)	35 (100)	1060

CFC Sales

To gain a real understanding of the effects of potential regulations on the CFC industry, we would ideally like to have CFC sales data for the individual firms and total company sales data. Since these data are not available, estimation techniques are necessary.

The apportionment of capacity to each producer in Table V-2 can be useful for determining the historical revenues derived from CFC sales. If the amount of each CFC sold historically is known, the apportionment scheme can be used, together with CFC prices, to determine the CFC sales revenue realized by each producer.

In the previous subsection, estimated capacities for each CFC were apportioned to each producer based on available capacity data and historical production figures. The 1977 sales of each CFC can be apportioned to the individual firms according to the percentage allocations of Table V-2. Although this table was developed on the basis of 1978 estimated capacities, it should be applicable to 1977 as well.

CFC pricing information is sparse and often does not refer to the actual price at which the CFC was sold.[1] Reference 3 gives the sales value and amount sold for CFC-11, CFC-12, and CFC-22 for 1970 through 1977. These values are shown in Table V-3 and exclude any revenue derived from sale as an intermediate. Prices for CFC-11, CFC-12, and CFC-22 changed only slightly from 1976 to 1977.

Table V-3

CFC SALES AND SALES VALUE[a]

	CFC-11		CFC-12		CFC-22	
Year	10^6 Pounds	Million $	10^6 Pounds	Million $	10^6 Pounds	Million $
1976	239	81.6	371	151.4	126	88.8
1977	197	66.9	340	135.9	129	88.1

[a]The values in this table were taken from Reference 3.

[1]As will be seen shortly, CFC is often priced according to size of purchase. Thus, unknown amounts are purchased at prices which have a considerable variance.

Unfortunately, the values of sales for CFC-113 and CFC-114 are unavailable. Table III-3 gave our estimates of the quantities of these two CFCs sold in 1977. Using this information in conjunction with 1977 CFC-113 and CFC-114 prices, a value of sales could be determined for each. Table V-4 gives our estimates of historical CFC-113 bulk prices and the only available CFC-114 price for the historical period. Use of these bulk prices will almost certainly lead to an underestimation of sales value. Nevertheless, the 1977 CFC-113 price of 56 cents per pound results in a 1977 CFC-113 sales value of 45.4 million dollars. Using 65 cents per pound as the CFC-114 selling price leads to a sales value of 12.4 million dollars.

Table V-4

CFC HISTORICAL PRICES--1970-1977

(cents per pound)

Year	CFC-113[a]	CFC-114
1970	40	--
1971	40	--
1972	40	--
1973	38.4	--
1974	43.3	--
1975	48.5	65[b]
1976	52	--
1977	56	--

[a]These prices for CFC-113 are bulk prices.

[b]A "1974" price for CFC-114 and the other CFCs is given in Reference 2. These prices are 35, 42, 63, 63, and 65 for CFC-11, CFC-12, CFC-22, CFC-113, and CFC-114 respectively. The report is dated December 1975, and comparison with the prices implied in Table V-3 indicates that these are probably actually 1975 prices. Prices for CFC-114 for the other years are not available.

Table V-5 shows the allocation of the 1977 sales for the five CFCs to each producing firm. The values were derived by assuming that sales value can be apportioned according to the portion of capacity held by each producer as given in Table V-2.[1] The 1977 CFC sales of each firm may be more meaningful when compared with total company sales, as shown in Table V-6.

The limitations of Table V-6 in representing the actual sales attributable to each firm are obvious. For example, it is true that all of Racon's sales are from sales of CFCs. The values of Table V-6 indicate that direct sales of CFC-11, CFC-12, and CFC-22 account for only about 55 percent of Racon's total sales. A number of factors could contribute to the understatement of Racon's sales and also to the understatement of the sales of all producers. These factors are discussed in Appendix F.

Table V-5

1977 CFC SALES

(millions of dollars)

Producer[a]	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114	Total
Allied	14.7	28.6	17.5	15.0	4.1	79.9
DuPont	38.2	76.2	45.6	30.4	8.3	198.7
Kaiser	6.0	12.2	7.0	--	--	25.2
Pennwalt	6.7	13.6	7.9	--	--	28.2
Racon	1.3	5.4	9.6	--	--	16.4
Total	66.9	136.0	72.7	45.4	12.4	348.4

[a]Assumes prices of 34 cents per pound for CFC-11, 40 cents per pound for CFC-12, 68 cents per pound for CFC-22, 56 cents per pound for CFC-113, and 65 cents per pound for CFC-114.

[1]This allocation method is based on the assumption that the amount of CFC produced by each firm is directly proportional to the fraction of total capacity held by that firm. This may not be valid in that some firms may produce at greater than stated capacity, and others at less than stated capacity.

Table V-6

1977 CFC AND TOTAL SALES

(millions of dollars)

Producer	CFC Sales	Total Sales[a]	CFC Percent of Total
Allied	79.9	2922.8	2.7
DuPont	198.7	9434.8	2.1
Kaiser	25.2	2179.6	1.2
Pennwalt	28.2	834.9	3.4
Racon	16.4	29.7	55.2[b]

[a]Total sales were obtained from *Moody's Industrial News Report*, Vol. 49, 1978.

[b]Racon's CFC sales are actually 100 percent of total sales.

PRECURSOR CHEMICAL PRODUCERS

The market for the chemicals which are precursors to CFC manufacture is more difficult to assess than the CFC market itself. The CFCs are the end product in a long chain of production involving a number of chemical processes. Many of the chemicals in this chain can be manufactured using two or more different processes, and most are used for a variety of purposes in addition to CFC manufacture. The details of the capacity allocation to the producers of each precursor chemical are given in Appendix G.

The results of the allocation indicate that the CFC manufacturers are heavily back-integrated into precursor production. Table V-7 indicates the magnitude of this involvement for each precursor chemical. No year is given in this table since the capacity allocations for the precursor chemicals were often given for different years. It should be stressed that the values of this table refer to precursor chemical production for CFC manufacture and not industry-wide precursor chemical production.

Of the CFC producers, the two largest, DuPont and Allied, are the most heavily integrated into manufacture of the precursor chemicals

considered here.[1] Two points to note are that Racon does not produce any of the precursor chemicals, and that CS_2 is not produced by any of the CFC manufacturers according to Table V-7.[2]

If future CFC production were limited, many of the precursor chemical producers who are not CFC manufacturers would also be significantly affected. Dow Chemical, the largest producer of the three chlorocarbons and Cl_2, would undoubtedly be one of these. Other companies which appear to be heavily involved in precursor production include Stauffer and Vulcan Materials.

Table V-7

PRECURSOR CHEMICAL PRODUCTION FOR CFCs

(millions of pounds)

Producer	CCl_4	HF	$CHCl_3$	C_2Cl_4	CS_2	Cl_2
Allied	151	98	52	--	--	318
DuPont	399	88	--	67	--	670
Kaiser	--	60	--	--	--	8
Pennwalt	--	30	--	--	--[a]	16
Racon	--	--[b]	--	--	--	--
Other	158	6	207	33	140	558
Total	708	282	259	100	140	1570[c]
CFC Producers' Percent of Total	78	98	20	67	0	64

[a] Pennwalt does produce CS_2, although not for CCl_4.

[b] There are other HF producers whose HF does not go toward CFC manufacture.

[c] This value excludes the production by the paper companies as discussed in Appendix G.

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[1] If other precursor chemicals were included, the other CFC producers might show the back integration as markedly as DuPont and Allied.

[2] The lack of CS_2 back integration reflects the fact that most of the CCl_4 used in CFC manufacture is not produced using CS_2.

VI. FUTURE PRODUCTION AND THE EFFECTS OF POLICY ACTION

The relationships developed here for determining CFC and precursor chemical production based on a particular level of CFC use can be used to estimate future requirements. In this section, we present projections of base case 1990 CFC end use. We also provide CFC production estimates based on industry supplied data and the implied precursor chemical requirements. We then examine five scenarios for reducing CFC emissions and discuss the implications of each on the CFC and precursor chemical producing industries.

1990 CFC END USE

In Reference 8, projections of 1990 base case CFC use for most CFC applications[1] are developed. These data are shown in Table VI-1.[2] The analyzed applications did not include those in which CFC-22 is heavily used (for example, home air-conditioning), since that CFC is thought to pose less of a hazard to the ozone layer than the fully halogenated CFCs.

CFC PRODUCTION AND SALES

Two knowledgeable industry sources provided us with data from which projections of CFC production could be derived. The techniques developed here for relating CFC production to the CFC available for use were then employed. Table VI-2 shows these estimates of future production and the amount of CFC available for use.

The values of CFC-11 for use in analyzed applications in Table VI-1 conflict with the projections of use in Table VI-2. The large variation in the production data supplied by industry sources for this CFC might account for the discrepancy.

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[1] The analyzed product areas account for about three-quarters of total CFC use.

[2] Reference 8 provides a detailed description of the techniques used to derive the data.

Table VI-1

ESTIMATED NONAEROSOL CFC END USE--1990

(millions of pounds)

Analyzed Applications	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114
Flexible Foam	72	--	--	--	
Solvents[a]	--	--	--	147	
Rigid Foams					
Urethane	154	5	--	--	
Non-urethane	8	59	--	--	1
Mobile Air Conditioning	--	125	--	--	
Other Refrigeration					
Chillers	14	6	4	--	2
Home Refrigerators and Freezers	--	9	--	--	--
Retail Food	--	10	1	--	--
Miscellaneous					
Liquid Fast Freezing	--	15	--	--	--
Sterilants	--	40	--	--	--
Other	4	11	--	--	--
TOTAL	252	280	5	147	3

SOURCE: Values were taken from Table 3.3 of Reference 8.

NOTE: Uses reported for individual applications exclude: about 7 million pounds of CFC-22 and 8 million pounds of CFC-115 used to form CFC-502; 2 million pounds of CFC-12 and less than 1 million pounds of CFC-152a used to form CFC-500.

[a]Refrigeration and other relatively small miscellaneous uses of CFC-113 are included in the solvents data.

Reference 9 indicates that CFC-12 is used in mobile and industrial refrigeration applications. These uses could account for the difference of 47 million pounds in the total CFC-12 figure of Table VI-1 and the end use value of Table VI-2.

The accuracy of the CFC-22 end use projections of Table VI-2 cannot be confirmed by comparison with the value of Table VI-1 since Reference 8 analyzed very few CFC-22 applications.

The end use values for CFC-113 in Tables VI-1 and VI-2 show perfect agreement since projections for both estimates were derived using the same data. The same holds true for CFC-502 end use, which is referred to in the note to Table VI-1.

Table VI-2

ESTIMATED NONAEROSOL CFC PRODUCTION AND END USE--1990

(millions of pounds)

CFC	Production	End Use[a]
CFC-11	262	228
CFC-12	363	327
CFC-22	385	265
CFC-113	147	147[b]
CFC-114	32	25
CFC-502	16	15

SOURCE: Industry supplied data and calculations as described in the text.

[a]The values for end use were calculated under the assumption that use will continue to be the same fraction of production as in 1976.

[b]The end use values for CFC-113 include estimates of imports, while those for the other CFCs do not.

The value for 1990 end use of CFC-114 in Table VI-2 is far higher than the total value for analyzed uses in Table VI-1. The analyzed applications do not include intermediate use of CFC-114 for the production of CFC-115. Most of this intermediate use is reflected in the difference between the values for production and end use in Table VI-2. There are numerous specialty applications in which CFC-114 acts as a refrigerant. Furthermore, the CFC is used in various exempted aerosol applications, including some for defense purposes. Although there are no available data on these uses, they may account for the balance of CFC-114 end use.

The 1990 values for CFC production given in Table VI-2 provide the basis for considering the future CFC production capacity requirements. As mentioned earlier, the design capacity of a particular production plant is only an approximation to the amount of the chemical that is actually produced. Production of a chemical may be less than the design capacity if the capacity is not fully utilized. Alternatively, actual production may exceed the design capacity, sometimes by as much as 100 percent. Although the "rule of thumb" which indicates that design capacity remains about 15 percent ahead of actual production is useful, it is not necessarily always accurate. Industry sources indicate that, in certain cases, plants may be run at 200 percent of rated design capacity. Thus, any assessment of the adequacy of current capacity for future production requirements is necessarily somewhat speculative.

The values of Table VI-2 indicate that combined 1990 CFC-11/CFC-12 production will be 625 million pounds. Existing capacity of CFC-11/CFC-12 plants is about 680 million pounds according to the values of Table V-2. This implies that if no policy action for limiting CFC emissions is taken prior to 1990, current capacity will be sufficient to produce CFC-11 and CFC-12 through 1990.

By 1990, CFC-22 production is estimated to be 385 million pounds in the absence of policy action. The 1977 CFC-22 capacity cited in Table V-2 is 230 million pounds. Some existing facilities were designed to produce either CFC-11/CFC-12 or CFC-22 by simply varying the precursor chemical feed. These plants could produce a mix of CFC-11/CFC-12 and CFC-22. The 230 million pounds of CFC-22 capacity together with the 55 million pounds of excess CFC-11/CFC-12 capacity would not be adequate to produce 385 million pounds of CFC-22 in 1990. However, it is certainly possible that all plants could be run at higher than design capacity. It seems reasonable to assume that existing capacity will probably be adequate through 1990, but that shortly thereafter, additional capacity will be necessary.

Current CFC-113/CFC-114 capacity is about 150 million pounds according to the values of Table V-2. Combined CFC-113/CFC-114 production in 1990 in the absence of policy action will total 179 million

pounds. The production exceeds the existing design capacity by only about 19 percent. Moreover, industry sources indicate that it takes less capacity to produce one pound of CFC-113 than it does to produce one pound of CFC-114. The same reasoning may also apply to CFC-11/CFC-12 production. It seems reasonable to conclude that the current capacity will probably suffice for the 1990 production levels, but additional capacity will likely be needed a short time later.

Capacity for CFC-502 need not be considered. This CFC is produced by combining CFC-22 and CFC-115 which is in turn produced using CFC-114. The 1990 production estimates of CFC-114 and CFC-22 given in Table VI-2 include the CFC-114 used to manufacture CFC-115 and the CFC-22 combined with it to form CFC-502.

PRECURSOR CHEMICAL PRODUCTION

Based on the CFC production levels of Table VI-2 and the methods developed in previous sections, the 1990 baseline precursor chemical requirements can be derived. These are shown in Table VI-3.

The values of Table VI-3 reflect only the amount of each precursor chemical required for CFC manufacture. They do not include requirements for other applications. In other words, the values of Table VI-3 represent the baseline 1990 precursor chemical requirements for the CFC production of Table VI-2.[1]

By 1990, the baseline HF requirements for CFC production will be 422 million pounds. According to the values of Table III-5, in 1976, 46 percent of the HF went toward CFC manufacture. Assuming this same percentage to hold through 1990, the total HF requirement in that year would be about 900 million pounds. If the "rule of thumb" that plant capacity is 15 percent higher than production is a reasonable estimating tool, HF capacity in 1990 should be about

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[1] Values for HF, C_2Cl_4, $CHCl_3$, and CS_2 differ from those presented in Table A-4 of Reference 8. In this case, precursor chemicals for CFC-22 and CFC-114 are included, whereas they were not in Reference 8.

Table VI-3

ESTIMATED PRECURSOR CHEMICAL
AND BYPRODUCT PRODUCTION--1990

(millions of pounds)

Year	HF	CCl_4	C_2Cl_4	$CHCl_3$	CS_2	Cl_2	HCl
1990	422	771	167	558	152	2224	1534

SOURCE: Derived as explained in the text.

1050 million pounds to produce the required HF. Since this is significantly higher than the 1977 capacity of 683 million pounds in Table G-2, HF capacity will probably be added by 1990.[1]

The values of Table VI-3 indicate that, by 1990, baseline requirements of CCl_4 will be 771 million pounds. Assuming this value represents 88 percent of total 1990 CCl_4 production and adopting the "15 percent rule of thumb," 1990 CCl_4 capacity should be about 1000 million pounds. The total 1977 CCl_4 capacity (1205 million pounds) given in Table G-1 should therefore by adequate through 1990.[2]

The 1990 C_2Cl_4 baseline requirement for CFC manufacture of 167 million pounds leads to an implied capacity of about 1130 million pounds assuming the "15 percent rule of thumb," and that 17 percent of C_2Cl_4 will be devoted to CFC manufacture in that year. The 1977 total C_2Cl_4 capacity of 1180 million pounds given in Table G-3 should be sufficient through that year.

The $CHCl_3$ baseline requirement in 1990, according to Table VI-3, will be 558 million pounds. If 86 percent of the $CHCl_3$ goes toward CFC production in that year, the implied capacity will total about 750 million pounds. The current total capacity of approximately

[1] Even more capacity would be necessary if Kaiser and Stauffer were to close their HF facilities.

[2] If FMC closes its facility, however, the capacity would not be adequate.

300 million pounds (Table G-3) would certainly be inadequate to satisfy the need. To meet the 1990 requirement, current $CHCl_3$ capacity would have to approximately double by that year.

According to Table VI-3, 1990 baseline CS_2 requirements for CFC manufacture will be 152 million pounds, only slightly larger than the 1977 production of 140 million pounds. Existing capacity should prove sufficient to satisfy the need.

Table VI-3 shows 1990 baseline Cl_2 requirements for CFC production as 2224 million pounds. Assuming that 9 percent of the Cl_2 is used for CFC manufacture in that year, the implied 1990 capacity would be about 28,400 million pounds, about 6000 million pounds higher than the 1977 capacity (Table G-5). Because this is only a small percentage of the design capacity, Cl_2 capacity for CFC manufacture probably will not be added before that time. Table VI-3 also illustrates that in 1990, as a result of the CFC and precursor chemical production requirements, there will be 1534 million pounds of HCl manufactured. This may or may not be a cost advantage depending on the market for HCl at that time.

The base line precursor chemical requirements serve as a basis for determining the impacts on the producers if no policy action is taken. However, in the event that policies for limiting emissions are adopted, precursor chemical requirements will also be reduced.

FUTURE POLICY ACTION

In Reference 8, two general policy strategies for reducing future emissions are discussed. The first strategy, mandatory controls, involves setting rules and regulations requiring firms to limit emissions by the use of specific technologies such as recovery and recycle of CFC, equipment improvements, or chemical substitution. The second strategy, economic incentives, entails manipulating CFC prices so that it becomes profitable for firms to reduce emissions.

The implications of five policy designs involving these two strategies were examined in Reference 8. The first, the benchmark controls, is a mandatory control strategy. The other four policy

designs are economic incentive strategies. Two of these, the constant price design and the cost-minimizing design, achieve the same reduction in emissions obtained through mandatory controls, about a 15 percent reduction in emissions between 1980 and 1990. The third economic incentives strategy is a low-growth scenario in which emissions would be reduced slightly more than under mandatory controls. The final economic incentives strategy is zero-growth, which would be equivalent in cumulative emissions reduction to prohibiting growth in CFC use after 1980. A complete description of the features of each policy is available in Reference 8.

Each of the five policies leads to a reduction in CFC emissions, and thereby, to a reduction in CFC use. Table VI-4 presents these CFC use reductions for the various policy cases for 1990. It should

Table VI-4

REDUCTION IN CFC USE UNDER BENCHMARK CONTROLS AND FOUR ECONOMIC INCENTIVE POLICY DESIGNS--1990

(millions of pounds)

Policy Design	CFC-11	CFC-12	CFC-113	CFC-114
Benchmark controls	40.5	20.3	32.5	-8.8
Economic Incentives Policies That Achieve The Benchmark Reductions				
Constant price design	30.3	11.9	49.3	-8.8
Cost-minimizing design	37.5	17.6	56.1	-8.8
Economic Incentives Policies for Low- and Zero-Growth				
Low-growth	57.8	36.4	79.3	-8.8
Zero-growth	57.8	36.4	79.3	-8.8

SOURCE: Table A-1 of Reference 8.

be emphasized that Reference 8, from which the values of Table VI-4 were taken, considered policies that would reduce CFC use only in the applications analyzed in that document. Since no applications using CFC-114 were analyzed, the table shows no reduction in CFC-114 resulting from the policy actions.

The precursor chemical requirement reductions that correspond to the CFC reductions are shown in Table VI-5. The values were determined using the techniques developed here for relating CFC to precursor chemical production.

The values of Table VI-5 show an increase in $CHCl_3$ requirements for all policy designs. This occurs because in each design, there is a control strategy involving the substitution of CFC-502 for CFC-12

Table VI-5

REDUCTION IN PRECURSOR CHEMICAL REQUIREMENTS--1990
(millions of pounds)

Policy Design	HF	CCl_4	C_2Cl_4	$CHCl_3$	CS_2	Cl_2
Benchmark controls	21	82	24	-7	16	143
Economic Incentives Policies That Achieve the Benchmark Reductions						
Constant price design	17	57	40	-7	11	122
Cost-minimizing design	27	74	46	-7	15	155
Economic Incentives Policies for Low- and Zero-Growth						
Low-growth	46	128	68	-7	25	260
Zero-growth	46	128	68	-7	25	260

SOURCE: Derived as explained in the text.

in all new medium-temperature retail food applications. Since CFC-502 is a combination of CFC-22 and CFC-115, substitution of CFC-502 for CFC-12 leads to an increased demand for $CHCl_3$ used to manufacture CFC-22.

The results of Table VI-5 are perhaps more meaningful when compared with the future baseline precursor chemical requirements, assuming no policy action is taken (Table VI-3). The percentage reductions in precursor chemical requirements for CFC manufacture and for all use under each of the policy designs over the baseline requirements are given in Table VI-6.[1]

The largest percentage reduction is shown for C_2Cl_4 in both the low-growth and zero-growth cases. If, in 1990, the same percent of C_2Cl_4 goes toward CFC production as in 1977, then the reduction will only affect 6 percent of total C_2Cl_4 production.[2] In fact, the only precursor chemical for which total production would decline more than 6 percent over expected baseline levels is CCl_4. Assuming 88 percent of CCl_4 production is still devoted to CFC manufacture in 1990, total CCl_4 production would decline about 15 percent over projected levels. If FMC (as indicated in the footnote to Table G-1) indeed closed its CCl_4 facility, the 1990 capacity requirement if either the low-growth or the zero-growth policies were adopted would be about the same as the current capacity available.

In 1976, aerosol applications of CFCs generated a significant share of the market for each of the precursor chemicals except chloroform. This part of the precursor chemical market has now virtually disappeared in the wake of the aerosol ban. It appears that the effects of CFC nonaerosol regulation would be quite modest in comparison with the effects of the aerosol ban. The largest impact of nonaerosol regulations would occur in the CCl_4 market, where the reduction in total

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[1] The values for Table VI-6 differ from those of Table A-6 of Reference 8. Since this reference does not include baseline requirements for CFC-22 and CFC-114 production, only the values for CCl_4 and CS_2 agree with those presented here.

[2] Since the assumption is that only 17 percent of C_2Cl_4 went toward CFC manufacture, only 6 percent reduction in C_2Cl_4 total production would result.

Table VI-6

PERCENT REDUCTION IN PRECURSOR CHEMICAL REQUIREMENTS--1990

(millions of pounds)

Policy Design	FOR CFC PRODUCTION						FOR ALL USE[a]					
	HF	CCl_4	C_2Cl_4	$CHCl_3$	CS_2	Cl_2	HF	CCl_4	C_2Cl_4	$CHCl_3$	CS_2	Cl_2
Benchmark Controls	5	11	14	-1	11	6	2	10	2	-1	3	1
Economic Incentives Designs that Achieve The Benchmark Reduction												
Constant Price Design	4	7	24	-1	7	5	2	6	4	-1	2	--[b]
Cost-Minimizing Design	6	10	28	-1	10	7	3	7	5	-1	3	1
Economic Incentives Designs Corresponding to Low Growth												
Low-Growth	11	17	41	-1	16	12	5	15	7	-1	4	1
Zero-Growth	11	17	41	-1	16	12	5	15	7	-1	4	1

SOURCE: Calculations explained in the text.

[a]Calculations assume that 46 percent of the HF, 88 percent of CCl_4, 17 percent of C_2Cl_4, 86 percent of $CHCl_3$, 26 percent of CS_2, and 9 percent of Cl_2 are used in CFC manufacture.

[b]Less than 1 million pounds.

annual production could be as high as 15 percent. For the other precursor chemicals, the effects of nonaerosol CFC regulation would generally amount to less than a 7 percent reduction in the overall markets.

VII. CONCLUSIONS

The aerosol ban has had a significant effect on the CFC and precursor chemical producing industries. Production of CFC-22 and CFC-113, both of which were not widely used in aerosol products, has steadily increased. In the absence of policy action between now and 1990, growth for the two CFCs will continue. Alternatively, production of CFC-11, CFC-12, and CFC-114, all of which were used as propellants, will not again reach 1976 levels until about 1990.

In the absence of any policy action, we anticipate continued growth in $CHCl_3$, C_2Cl_4, HF, and production of CCl_4 and CS_2 to have been adversely affected by the aerosol ban. Comparison of the values of Tables VI-3 and III-4 indeed indicates continuing growth for $CHCl_3$, C_2Cl_4, HF, and Cl_2, while production of CCl_4 and CS_2 will not reach 1976 levels again until about 1990. Of the two precursor chemicals, CCl_4 was affected more severely by the aerosol ban. This follows from the fact that almost all of the CCl_4 produced is used in CFC manufacture, whereas only about one-fourth of the CS_2 production is devoted to this use.

The effects of two general policy strategies for limiting non-aerosol CFC emissions on precursor chemical production were examined. One of these, a mandatory control strategy, requires firms to reduce emissions by the use of specific technology. The second strategy, economic incentives, involves manipulation of CFC prices so that it becomes desirable to limit emissions. CFC emissions reductions that would occur under five policy designs were used to determine the corresponding reductions in precursor chemical production requirements. The first design, the benchmark controls, is a mandatory control strategy; the other four designs are economic incentive strategies. The five policy designs would lead to CFC emission reductions of between 15 and 30 percent over the period 1980 to 1990.

The aerosol ban that primarily affected use of CFC-11 and CFC-12 reduced the production requirements of those precursor chemicals used exclusively in their manufacture, CCl_4 and CS_2. The five policy designs for limiting nonaerosol emissions would lead to reductions in the use of CFC-113 in addition to CFC-11 and CFC-12. Production requirements of several precursor chemicals--HF, CCl_4, C_2Cl_4, CS_2, and Cl_2--would also decline. The most stringent policy designs for limiting emissions are the zero-growth and low-growth policies. Under these policies, 1990 CCl_4 production would be about 15 percent less than under base case projections which assume no policy action will be taken. Production of the other precursor chemicals would decline by 7 percent at most under the two policy designs. That the greatest impact would be felt in the CCl_4 market is not surprising. A very large amount of the total CCl_4 produced, 88 percent, is used in the manufacture of CFCs. The very modest impact on the other precursor chemicals is also to be expected since much smaller percentages of total production are devoted to CFC manufacture.

The techniques developed in this document have wide applicability. They can be used to assess the effects of any level of CFC emissions reduction on the precursor chemical production industries. An emissions limitation imposed on a particular CFC implies a corresponding limitation on its use. Reduced use leads to a reduction in CFC production which, in turn, leads to a reduction in precursor chemical requirements. This work provides the basis for translating a change in any one of the three variables, CFC use, CFC production, and precursor chemical production into a change in any one of the other variables.

Appendix A

PRECURSOR CHEMICALS FOR CFC PRODUCTION

The purpose of this appendix is to develop factors that can be used to calculate the amount of each precursor chemical used in CFC manufacture. Given a level of CFC production and a knowledge of the chemical equations and efficiency of the processes, this can be accomplished readily. The molecular weights of each compound necessary for the calculation are listed in Table A-1. For convenience, Table A-2 reproduces the chemical equations presented in Section II.

Table A-1

MOLECULAR FORMULAS AND WEIGHTS

Compound Name	Molecular Formula	Molecular Weight
carbon disulfide	CS_2	76.14
carbon tetrachloride	CCl_4	153.84
CFC-11	CCl_3F	137.38
CFC-12	CCl_2F_2	120.93
CFC-22	$CHClF_2$	86.48
CFC-113	$C_2Cl_3F_3$	187.39
CFC-114	$C_2Cl_2F_4$	170.94
chlorine	Cl_2	70.91
chloroform	$CHCl_3$	119.39
hydrogen fluoride	HF	20.01
hydrochloric acid	HCl	36.47
methyl alcohol	CH_3OH	32.04
perchloroethylene	C_2Cl_4	165.85
trichloroethylene	C_2HCl_3	131.39

Table A-2

CHEMICAL EQUATIONS FOR CFC MANUFACTURE

$CCl_4 + HF \rightarrow HCl + CCl_3F$ (CFC-11)	(A-1)
$CCl_4 + 2HF \rightarrow 2HCl + CCl_2F_2$ (CFC-12)	(A-2)
$a\ C_3H_6 + (7a-2b)Cl_2 \rightarrow (a-2b)CCl_4 + (a+b)C_2Cl_4 + 6a\ HCl$	(A-3)
$CS_2 + 2Cl_2 \rightarrow CCl_4 + 2S$	(A-4)
$CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl$	(A-5)
$CHCl_3 + 2HF \rightarrow 2HCl + CHClF_2$ (CFC-22)	(A-6)
$CH_4 + 3Cl_2 \rightarrow CHCl_3 + 3HCl$	(A-7)
$CH_3OH + 2Cl_2 \rightarrow CHCl_3 + HCl + H_2O$	(A-8)
$C_2Cl_4 + 3HF + Cl_2 \rightarrow C_2Cl_3F_3 + 3HCl$ (CFC-113)	(A-9)
$C_2Cl_4 + 4HF + Cl_2 \rightarrow C_2Cl_2F_4 + 4HCl$ (CFC-114)	(A-10)
$2C_2H_4 + 7Cl_2 \rightarrow C_2HCl_3 + C_2Cl_4 + 7HCl$	(A-11)

In addition to molecular weights, the calculations require knowledge of emissions and production process efficiencies. Generally, industry defines "process efficiency" as the product of an efficiency factor and an emissions factor. In this work, the efficiency factor will be considered to account for unreacted chemical inputs or undesirable byproducts, while the emissions factor will be assumed to address mechanical losses after reaction of raw materials.

CFC emissions from the production process have been estimated by knowledgeable sources at 2 percent of total production.[1] Since it is not known how this value varies depending on the CFC being produced, the 2 percent loss figure will be adopted here for all CFC manufacturing processes. Emissions in the production of the intermediate precursor chemicals are negligible according to industry sources. This is probably due to the stringent emissions standards for the chlorocarbons and also their much lower vapor pressures.

The second factor, the process efficiency, does vary somewhat according to the chemical being produced. Through conversations with industry individuals, we have made estimates of the magnitudes of these factors for each process. These are explained in the development of the factors for each precursor chemical below.

The general formula for calculating the precursor chemical factors is as follows:

$$\text{Factor} = \frac{\text{Precursor Molecular Weight}}{\text{CFC Molecular Weight}} \times \frac{1}{\text{Efficiency}} \times \frac{1}{(1-\text{fraction Emitted})}$$

INTERMEDIATE PRECURSOR CHEMICALS

CCl_4

Equations A-1 and A-2 may be used to determine the amount of CCl_4 needed to produce one unit each of CFC-11 and CFC-12. The

[1] These emissions are discussed in more detail in Section IV.

losses here are primarily due to CFC production emissions. The efficiency of producing CFC-11 and CFC-12 from CCl_4 is extremely high.

For CFC-11: $$\frac{153.84}{137.38} \times \frac{1}{.999} \times \frac{1}{.98} = 1.14$$

For CFC-12: $$\frac{153.84}{120.93} \times \frac{1}{.999} \times \frac{1}{.98} = 1.30$$

HF

Equations A-1, A-2, A-6, A-9, and A-10 may be used to calculate the amount of HF necessary per unit of CFC output. The efficiency of producing CFC-11 and CFC-12 from HF is significantly higher than that for producing CFC-22, CFC-113, and CFC-114.

For CFC-11: $$\frac{20.01}{137.38} \times \frac{1}{.995} \times \frac{1}{.98} = 0.15$$

For CFC-12: $$\frac{2 \times 20.01}{120.93} \times \frac{1}{.995} \times \frac{1}{.98} = 0.34$$

For HCFC-22: $$\frac{2 \times 20.01}{86.48} \times \frac{1}{.975} \times \frac{1}{.98} = 0.48$$

For CFC-113: $$\frac{3 \times 20.01}{187.39} \times \frac{1}{.975} \times \frac{1}{.98} = 0.34$$

For CFC-114: $$\frac{4 \times 20.01}{170.94} \times \frac{1}{.975} \times \frac{1}{.98} = 0.49$$

$CHCl_3$

In this case, only Equation A-6 is needed. The production of CFC-22 from $CHCl_3$ is extremely efficient, but to account for production of CFC-23, a minor co-product, a value of .97 has been used.

For CFC-22: $\frac{119.39}{86.48} \times \frac{1}{.97} \times \frac{1}{.98} = 1.45$

C_2Cl_4

Equations A-9 and A-10 are necessary. Production of CFC-113 and CFC-114 is not as efficient as the production of CFC-11 and CFC-12.

For CFC-113: $\frac{165.85}{187.39} \times \frac{1}{.98} \times \frac{1}{.98} = 0.92$

For CFC-114: $\frac{165.85}{170.94} \times \frac{1}{.98} \times \frac{1}{.98} = 1.01$

Cl_2

Equations A-9 and A-10 are again those which are needed. The consumption of Cl_2 in the manufacture of CFC-113 and CFC-114 is relatively inefficient.

For CFC-113: $\frac{70.91}{187.39} \times \frac{1}{.93} \times \frac{1}{.98} = 0.42$

For CFC-114: $\frac{70.91}{170.94} \times \frac{1}{.93} \times \frac{1}{.98} = 0.46$

PRELIMINARY PRECURSOR CHEMICALS

CS_2

The relevant equation is Equation A-4. As indicated previously, the emissions of CCl_4 are negligible.

For CCl_4: $\frac{76.14}{153.84} \times \frac{1}{.95} \times \frac{1}{1.00} = 0.52$

Cl_2

The necessary equations in this case are A-3, A-4, A-5, A-7, A-8, and A-11. Again, in each case, chlorocarbon emissions during the production process are considered negligible.

For $CHCl_3$ in Equation A-7: $$\frac{3 \times 70.91}{119.39} \times \frac{1}{.92} \times \frac{1}{1.00} = 1.94$$

For $CHCl_3$ in Equation A-8: $$\frac{2 \times 70.91}{119.39} \times \frac{1}{.92} \times \frac{1}{1.00} = 1.29$$

For CCl_4 in Equation A-4: $$\frac{2 \times 70.91}{153.84} \times \frac{1}{.95} \times \frac{1}{1.00} = 0.97$$

For CCl_4 in Equation A-5: $$\frac{4 \times 70.91}{153.84} \times \frac{1}{.96} \times \frac{1}{1.00} = 1.92$$

The Cl_2 factors for CCl_4 and C_2Cl_4 in Equation A-3 are more complicated to derive because of a and b. One way to determine values for these constants is to examine actual production for a given year. In 1973, 1047 and 706 million pounds of CCl_4 and C_2Cl_4 were produced respectively. Reference 1 states that 39 percent of CCl_4 capacity is based on Equation A-3.[1] Reference 2 asserts that 34 percent of C_2Cl_4 production is based on a process similar to Equation A-3.[1] It is a generally accepted fact that the inputs to Equation A-3 can be continuously varied to provide different proportions of C_2Cl_4 and CCl_4.

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[1] See Appendix B for a more complete discussion.

On this basis, values for a and b can be derived in the following way:

For CCl_4 produced in 1973: $1047 \times 0.39 = 408$

For C_2Cl_4 produced in 1973: $706 \times 0.34 = 240$

$$\frac{408}{(a - 2b)\quad 153.84} = \frac{240}{(a + b)\quad 165.85}$$

$$b = -0.22a$$

If a is assumed equal to 1, then b is -0.22 and Equation A-3 becomes:

$$C_3H_6 + 7.44\ Cl_2 \rightarrow 0.78\ C_2Cl_4 + 1.44\ CCl_4 + 6HCl$$

Of the 7.44 moles of Cl_2 required to produce C_2Cl_4 and CCl_4 in this equation, 63 and 37 percent were used to produce CCl_4 and C_2Cl_4 respectively. Thus, the factors for Cl_2 in this equation become:

For CCl_4 in Equation A-3: $$.63 \times \frac{7.44 \times 70.91}{1.44 \times 153.84} \times \frac{1}{.92} \times \frac{1}{1.00} = 1.63$$

For C_2Cl_4 in Equation A-3: $$.37 \times \frac{7.44 \times 70.91}{.78 \times 165.85} \times \frac{1}{.92} \times \frac{1}{1.00} = 1.64$$

One industry source recommends that the input hydrocarbon in this equation be treated as CH_2 and multiple units of CH_2. The factors resulting from this analysis do not differ significantly from those shown above.

The Cl_2 factor for C_2Cl_4 in Equation A-11 is also more difficult to obtain because C_2Cl_4 and C_2HCl_3 are co-produced. Reference 2 states that about 90 percent of the C_2CHl_3 and 63 percent of the C_2Cl_4

are manufactured using a method similar to Equation A-11. For 1973, Reference 3 gives total C_2HCl_3 and C_2Cl_4 production as 452 and 706 pounds respectively.

On this basis, Equation A-11 was used to manufacture 407 and 445 million pounds of C_2HCl_3 and C_2Cl_4 respectively. This implies that 54 and 46 percent of the Cl_2 in Equation A-11 went toward C_2HCl_3 and CCl_4 manufacture respectively. Thus, the Cl_2 factor becomes:

For C_2Cl_4 in Equation A-11:

$$.46 \times \frac{7 \times 70.91}{4 \times 165.85} \times \frac{1}{.96} \times \frac{1}{1.00} = 0.36$$

BYPRODUCT HCl

HCl is produced as a byproduct as a result of CFC manufacture according to Equations A-1, A-2, A-6, A-9, and A-10. It is also produced in the preparation of the chlorocarbons for CFC manufacture in Equations A-3, A-5, A-7, and A-8.[1] Factors for each of these equations are developed below. The efficiency of the HCl recovery process has been assumed to be 0.95 except in the case of $CHCl_3$ where it is estimated at 0.90.

From CFC-11: $$\frac{36.47}{137.38} \times .95 \times \frac{1}{.98} = 0.26$$

From CFC-12: $$\frac{2 \times 36.47}{120.93} \times .95 \times \frac{1}{.98} = 0.58$$

From CFC-22: $$\frac{2 \times 36.47}{86.48} \times .95 \times \frac{1}{.98} = 0.82$$

From CFC-113: $$\frac{3 \times 36.47}{187.39} \times .95 \times \frac{1}{.98} = 0.57$$

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[1]The HCl byproduct from Equation A-11 is not included here. See Section II.

From CFC-114: $\frac{4 \times 36.47}{170.94} \times .95 \times \frac{1}{.98} = 0.83$

From CCl_4 in Equation A-3: $.63 \times \frac{6 \times 36.47}{1.44 \times 153.84} \times .95 \times \frac{1}{1.00} = 0.59$

From CCl_4 in Equation A-5: $\frac{4 \times 36.47}{153.84} \times .95 \times \frac{1}{1.00} = 0.90$

From $CHCl_3$ in Equation A-7: $\frac{3 \times 36.47}{119.39} \times .90 \times \frac{1}{1.00} = 0.82$

From $CHCl_3$ in Equation A-8: $\frac{36.47}{119.39} \times .90 \times \frac{1}{1.00} = 0.27$

From C_2Cl_4 in Equation A-3: $.37 \times \frac{6 \times 36.47}{.78 \times 165.85} \times .95 \times \frac{1}{1.00} = 0.59$

Table A-3 summarizes the intermediate precursor chemical factors derived above. The preliminary precursor chemical factors are given in Table A-4. Finally, a summary of the factors for byproduct HCl is provided in Table A-5.

These factors have been determined on the basis of the production of one unit of product. It is a simple matter to multiply each factor by the production of each chemical in a given year to obtain the total amount of the precursor chemical which was used in the manufacture of each CFC or intermediate precursor chemical that year. Comparison of the factors determined for CCl_4, HF, $CHCl_3$ and C_2Cl_4 with those provided by two of the CFC manufacturers shows good agreement.

Table A-3

INTERMEDIATE PRECURSOR CHEMICAL FACTORS

(units of Precursor/Unit of CFC)

CFC Produced	CCl_4	HF	$CHCl_3$	C_2Cl_4	Cl_2
CFC-11	1.14	0.15	--	--	--
CFC-12	1.30	0.34	--	--	--
CFC-22	--	0.48	1.45	--	--
CFC-113	--	0.34	--	0.92	0.42
CFC-114	--	0.49	--	1.01	0.46

Table A-4

PRELIMINARY PRECURSOR CHEMICAL FACTORS

(units of Preliminary Precursor/
unit of Intermediate Precursor)

Intermediate Precursor Produced	CS_2	Cl_2
CCl_4	0.52	1.45[a]
$CHCl_3$	--	1.62[b]
C_2Cl_4	--	0.81[c]

[a] Calculated assuming 38, 39, and 23 percent of the CCl_4 for CFC production was manufactured according to Equations A-3, A-4, and A-5 respectively.

[b] Half the $CHCl_3$ was produced according to Equation A-7, and half according to Equation A-8.

[c] Calculated assuming 35 percent of the C_2Cl_4 used in CFC manufacture was produced according to Equation A-3, and 65 percent according to A-11.

Table A-5

BYPRODUCT HCl FACTORS

(Units of HCl/Unit of Chemical Produced)

Chemical Produced	HCl
CFC-11	0.26
CFC-22	0.58
CFC-22	0.82
CFC-113	0.57
CFC-114	0.83
CCl_4	0.43[a]
$CHCl_3$	0.55[b]
C_2Cl_4	0.21[c]

[a]Calculated assuming 38 percent of the HCl was produced according to Equation A-3 and 23 percent according to Equation A-5.

[b]Calculated assuming half the HCl was produced according to Equation A-7 and half according to Equation A-8.

[c]Calculated assuming 35 percent of the HCl was produced according to Equation A-3.

Appendix B

HISTORICAL PRECURSOR CHEMICAL PRODUCTION

The purpose of this appendix is to establish the amount of each precursor chemical used in CFC manufacture during the period 1970-1977.

INTERMEDIATE PRECURSOR CHEMICALS

The intermediate precursor chemicals that would be greatly affected by a change in CFC production were identified as CCl_4, HF, $CHCl_3$, and C_2Cl_4. Cl_2 would also be affected, although to a lesser extent. Each of these precursor chemicals is treated individually below.

CCl_4

Table B-1 shows total historical CCl_4 production and the amount that went toward CFC-11 and CFC-12 manufacture, derived using the factors of Appendix A. Reference 1 states that in 1973, 97.2 percent of CCl_4 went toward the production of CFC-11 (36.6 percent) and CFC-12 (60.6 percent). Table B-1 shows excellent agreement, indicating that 97 percent of the 1973 CCl_4 production was used in CFC manufacture: 36 percent for CFC-11, and 61 percent for CFC-12.

Table B-1

CCl_4 PRODUCTION FOR CFCs--1970-1977

(millions of pounds)

Year	Total[a]	For CFC-11[b]	For CFC-12[b]	Percent CCl_4 Used For CFC Production
1970	1011	278	488	76
1971	1009	294	507	79
1972	997	342	571	92
1973	1047	381	636	97
1974	1163	389	633	88
1975	906	308	511	90
1976	857	292	511	94
1977	809	243	465	88

[a] From Reference 3.

[b] Calculated using the factors 1.14 and 1.30 for CFC-11 and CFC-12 respectively, given in Appendix A, and the production values of Table III-1.

HF

The historical HF production and the portion going toward CFC manufacture are shown in Table B-2.

Values for total HF production for each year are not available. Reference 4 does state that, in 1973, 305 million pounds or 41.6 percent of total HF production went toward CFC production. This implies a 1973 total production of 733 million pounds. Assuming this value for total 1973 HF production, the estimates from Table B-2 imply that 44 percent of HF production was devoted to CFC manufacture, fairly close to Reference 4's 41.6 percent.

Reference 5 gives 1974 total HF production as 799 million pounds. On this basis, CFC manufacture accounted for 41 percent of total HF production.

The values for 1973 in Table B-2 also agree fairly well with Reference 4 which states that 55, 180, and 70 million pounds of HF went toward CFC-11, CFC-12, and CFC-22 production, respectively.

Table B-?

HF PRODUCTION FOR CFCs--1970-1977

(millions of pounds)

Year	For[a] CFC-11	For[a] CFC-12	For[b] CFC-22	For[c] CFC-113	For[c] CFC-114	Total for CFC Production
1970	37	128	48	15	17	245
1971	39	133	54	15	19	260
1972	45	149	59	17	21	291
1973	50	166	65	23	21	325
1974	51	166	68	24	22	331
1975	41	134	63	22	19	279
1976	38	134	82	24	18	296
1977	32	122	86	29	12	281

[a]Calculated using the factors 0.15 for CFC-11 and 0.48 for CFC-12 given in Appendix A, and the production values of Table III-1.

[b]Calculated using the factor 0.48 for CFC-22 given in Appendix A, and the production values of Table III-2.

[c]Calculated using the factors 0.34 for CFC-113 and 0.49 for CFC-114 given in Appendix A, and the production values of Table III-3.

$CHCl_3$

Table B-3 shows total historical $CHCl_3$ production and the portion that was used to manufacture CFC-22, determined using the factor derived in Appendix A.

The 1973 value of Table B-3 agrees fairly well with Reference 4 which gives the amount of $CHCl_3$ going toward CFC-22 production as 205 million pounds or 81 percent of total $CHCl_3$ production.

Table B-3

$CHCl_3$ PRODUCTION FOR CFCs--1970-1977

(millions of pounds)

Year	Total[a]	For CFC-22[b]	Percent Used For CFC-22 Production
1970	240	145	60
1971	231	162	70
1972	235	178	76
1973	253	197	78
1974	302	204	68
1975	262	191	73
1976	292	247	85
1977	302	260	86

[a] From Reference 3.

[b] Calculated using the factor 1.45 for CFC-22 from Appendix A, and the production values of Table III-2.

C_2Cl_4

Historical production of C_2Cl_4 and the amounts that were used to manufacture CFC-113 and CFC-114 are given in Table B-4.[1]

Reference 4 states that of the total 1973 C_2Cl_4 production of 706 million pounds, 58 million pounds went toward the manufacture of CFCs. Table B-4 indicates almost twice that amount. It is possible that Reference 1 was referring only to C_2Cl_4 for CFC-113.

Table B-4

C_2Cl_4 PRODUCTION FOR CFCs--1970-1977

(millions of pounds)

Year	Total[a]	For CFC-113[b]	For CFC-114[b]	Percent Used For CFC Production
1970	707	40	35	11
1971	705	40	39	11
1972	734	47	43	12
1973	706	63	43	15
1974	734	66	44	15
1975	679	60	39	15
1976	669	66	37	15
1977	603	77	25	17

[a]Historical production was taken from Reference 3.

[b]Calculated using the factors 0.92 for CFC-113 and 1.01 for CFC-114 from Appendix A, and the production values of Table III-3.

[1]A large portion of C_2Cl_4 is used as a solvent; in fact, it is one of the potential substitutes for CFC-113.

Cl_2

This compound is used as an intermediate precursor chemical directly in the manufacture of CFC-113 and CFC-114. Table B-5 shows historical production of Cl_2 for the two CFCs.

Reference 4 gives total 1973 Cl_2 production as 20,804 million pounds, while Reference 5 states that in 1974, 21,236 million pounds of Cl_2 was produced. Thus, an almost negligible percent of the total Cl_2 is used to produce CFC-113 and CFC-114. A much larger portion of Cl_2 is used as a preliminary precursor chemical as discussed below.

Table B-5

Cl_2 PRODUCTION FOR CFCs--1970-1977

(millions of pounds)

Year	For CFC-113[a]	For CFC-114[a]	Total Used For CFC Production
1970	18	16	34
1971	18	18	36
1972	21	20	41
1973	29	20	49
1974	30	20	50
1975	27	18	45
1976	30	17	47
1977	35	12	47

[a]Calculated using the factors 0.42 for CFC-113 and 0.46 for CFC-114 of Appendix A, and the production values of Table III-3.

PRELIMINARY PRECURSOR CHEMICALS

The significant preliminary precursor chemicals were identified in Section II as CS_2 and Cl_2. They are used to make other chemicals which, in turn, are used to produce CFCs. Both CS_2 and Cl_2 used in this capacity are discussed below.

CS_2

CS_2 is used to make CCl_4 which goes toward CFC-11 and CFC-12 manufacture. The calculation of the amounts of preliminary precursor chemicals used in CFC manufacture is not as straightforward as that of the intermediate precursor chemicals. In general, the only method for CFC preparation is one which uses the intermediate precursor chemical, but the intermediate precursors are often produced from the preliminary precursor chemicals by several different processes. For example, CCl_4 is produced using three different methods, only one of which involves CS_2.

According to Reference 1, about 38 percent of the CCl_4 capacity uses the process described by Equation II-4. It will be assumed that 38 percent of CCl_4 is produced using CS_2 and further, that the same percentage holds for the CCl_4 used in CFC-11 and CFC-12 manufacture.

On this basis, Table B-6 shows total historical CS_2 production and the amount which went toward CFC manufacture. Reference 4 gives 1972 CS_2 production as 775 million pounds, and Reference 5 gives 1974 CS_2 production as 772 million pounds. From Table B-6, it can be determined that CS_2 production for CFC manufacture represented 23 and 26 percent of total production for 1972 and 1974 respectively. These values agree well with Reference 4 which states that 25 percent of the CS_2 was used to produce CFCs.

Cl_2

In the discussion of intermediate precursor chemicals, the amount of Cl_2 which is used to produce CFC-113 and CFC-114 was calculated. These are the only CFCs which directly employ Cl_2 in

Table B-6

CS_2 PRODUCTION FOR CCl_4--1970-1977

(millions of pounds)

Year	For CCl_4[a]	For CFC-11[a]	For CFC-12[a]	Total Used For CFC Production
1970	200	55	96	151
1971	199	58	100	158
1972	197	68	113	181
1973	207	75	126	201
1974	230	77	125	202
1975	179	61	101	162
1976	169	58	101	159
1977	160	48	92	140

[a]Determined using the factor of 0.52 of Appendix A and the values of Table B-1 and multiplying by 0.38.

their manufacture.[1] Indirectly, however, Cl_2 is necessary in the preparation of some of the intermediate precursor chlorocarbons, $CHCl_3$, CCl_4, and C_2Cl_4.

One knowledgeable source indicates the fraction of $CHCl_3$ produced according to Equation II-9 is 50 percent or more. It will be assumed here that half the $CHCl_3$ is manufactured using this process. Table V-7 shows the amount of Cl_2 which went toward $CHCl_3$ and, ultimately, CFC-22 manufacture.

[1]See Equations II-10 and II-11.

Table B-7

Cl_2 PRODUCTION FOR $CHCl_3$--1970-1977
(millions of pounds)

Year	For $CHCl_3$	For CFC-22[a]
1970	388	234
1971	373	262
1972	380	287
1973	409	318
1974	488	329
1975	423	308
1976	472	399
1977	488	420

[a]Calculated using an equal weighting of the factors 1.94 and 1.29 and the values of Table B-3.

Table B-7 is in reasonable agreement with Reference 4 which states that in 1973, 368 and 454 million pounds of Cl_2 were used for CFC-22 and $CHCl_3$ production, respectively, Given total Cl_2 production of 20,804 million pounds in 1973 (Reference 6) and 21,236 million pounds in 1974 (Reference 5), only about 2 percent of Cl_2 was used in CFC-22 manufacture.

CCl_4 can be prepared by three methods described by Equations II-3, II-4, and II-5. According to Reference 7, about 23 percent of the CCl_4 capacity is available to produce CCl_4 by Equation II-5, 38 percent by Equation II-4, and 39 percent by Equation II-3. It will be assumed that the percentage capacity devoted to each process is the same as the percentage actually used in CCl_4 production. With this in mind, Table B-8 shows the amount of Cl_2 which was used historically to produce CCl_4 by the three methods, and finally, to produce CFC-11 and CFC-12.

Reference 4 gives the amount of Cl_2 which went toward CFC-11 and CFC-12 production in 1973 as 640 and 970 million pounds, respectively. The values of Table B-8 for 1973 are somewhat lower than

Table B-8

Cl_2 PRODUCTION FOR CCl_4--1970-1977
(millions of pounds)

Year	For CCl_4[a]	For CFC-11[a]	For CFC-12[a]	Total Used For CFC Production
1970	1462	402	706	1108
1971	1459	425	733	1158
1972	1442	495	826	1321
1973	1514	551	920	1471
1974	1682	562	915	1477
1975	1310	445	739	1184
1976	1239	422	739	1161
1977	1170	351	672	1023

[a]Determined using a weighting of 38 percent of the factor 1.63, 39 percent of the factor 0.97, and 23 percent of the factor 1.92 together with the values of Table B-1.

these numbers. From the total Cl_2 production given in References 5 and 6, it can be determined that about 8 percent of Cl_2 is used to manufacture CFC-11 and CFC-12.

Reference 1 disagrees somewhat with Table B-8 stating that 5.1 percent of Cl_2 production went toward the manufacture of CCl_4. A quick calculation indicates that this would be the case if all CCl_4 were produced using methane and Cl_2. However, Reference 7, an appendix to Reference 1, also gives the percentage breakdown of each of the three methods for CCl_4 production used in this work. We do not have an explanation for the discrepancy.

Cl_2 is used to produce C_2Cl_4 according to Equations II-3 and II-12. Reference 2 claims that 34 percent and 63 percent of the C_2Cl_4 are produced according to Equations II-3 and II-2, respectively.[1] Table B-9 gives the amount of Cl_2 required for C_2Cl_4 production which then translates into CFC-113 and CFC-114 manufacture.

[1]This reference also states that the remaining 3 percent of the C_2Cl_4 is produced using acetylene (C_2H_2), but industry sources indicate that this process is no longer used. We will assume here that 35 percent is manufactured according to Equation II-3 and 65 percent according to Equation II-12.

The percent of total Cl_2 used in the production of CFC-113 and CFC-114 is very small, less than 1 percent. Reference 4 states that the amounts of Cl_2 used to make C_2Cl_4 and the CFCs in 1973 were 1062 and 88 million pounds respectively. Table B-9 gives a value for C_2Cl_4 about half of this, but agrees well for the CFCs.

Table B-9

Cl_2 PRODUCTION FOR C_2Cl_4--1970-1977
(millions of pounds)

Year	For C_2Cl_4[a]	For CFC-113[a]	For CFC-114[a]	Total Used For CFC Production
1970	571	32	28	60
1971	570	32	32	64
1972	593	38	35	73
1973	570	51	35	86
1974	593	53	36	89
1975	549	48	32	80
1976	541	53	30	83
1977	487	62	20	82

[a]Determined using 35 percent of the factor 1.64 and 65 percent of the factor 0.36 together with the values of Table B-4.

BYPRODUCT HCl

The HCl produced in the manufacture of the CFCs is, as mentioned previously, an important consideration. The market for the HCl is dynamic; at times, demand for the chemical is heavy; at other times, neutralization or deepwelling must be used to dispose of it. Thus, HCl conditions may have a significant economic impact on production.

Table B-10 presents the amount of HCl which was produced historically in the manufacture of each of the CFCs according to Equations II-1, II-2, II-7, II-10, and II-11.

Table B-10

HCl PRODUCTION FROM CFCs--1970-1977

(millions of pounds)

Year	From CFC-11[a]	From CFC-12[a]	From CFC-22[b]	From CFC-113[c]	From CFC-114[c]	Total
1970	63	218	82	25	29	417
1971	67	226	92	25	32	442
1972	78	255	101	29	36	499
1973	87	284	112	39	36	558
1974	89	282	116	41	37	565
1975	70	228	108	37	32	475
1976	67	228	139	41	31	506
1977	55	208	147	48	21	479

[a]Determined using the factors of 0.26 for CFC-11 and 0.58 for CFC-12 of Appendix A and the values of Table III-1.

[b]Determined using the factor 0.82 for CFC-22 of Appendix A and the values of Table III-2.

[c]Determined using the factors 0.57 for CFC-113 and 0.83 for CFC-114 of Appendix A and the values of Table III-3.

Table B-11 shows the amount of HCl produced in CCl_4, $CHCl_3$, and C_2Cl_4 production for the manufacture of CFC-11/CFC-12, CFC-22, and CFC-113/CFC-114.

A summary of the amounts of each precursor chemical which historically went toward CFC manufacture is provided in Section III, Table III-4.

Table B-11

HCl PRODUCTION FROM PRECURSOR CHEMICALS--1970-1977

(millions of pounds)

Year	From CCl_4 For CFC-11[a]	From CCl_4 For CFC-12[a]	From $CHCl_3$ For CFC-22[b]	From C_2Cl_4 For CFC-113[c]	From C_2Cl_4 For CFC-114[c]	Total
1970	122	213	79	8	7	429
1971	129	222	88	8	8	455
1972	149	250	97	10	9	515
1973	167	278	107	13	9	574
1974	170	277	111	14	9	581
1975	135	223	104	12	8	482
1976	128	223	135	14	8	508
1977	106	203	142	16	5	472

[a]Determined using 39 percent of the factor 0.59 and 23 percent of the factor 0.90 and the values of Table B-1.

[b]Determined using 50 percent of the factor 0.82 and 50 percent of the factor 0.27 and the values of Table B-3.

[c]Determined using the factors of Appendix A and Table B-4.

Appendix C

HISTORICAL CFC APPORTIONMENT

The purpose of this appendix is to apply the method of allocating CFC to its various destinations after it is produced to the period 1970-1977. We first discuss the activities before the CFC is used, and then address aerosol use.

PRE-USE ACTIVITIES

Tables C-1 through C-5 summarize historical production, intermediate use, sales, emissions, exports, and nonaerosol use of the five CFCs. For CFC-113, Table IV-4 presents values for only production, sales, and nonaerosol use. A more detailed analysis of this CFC is provided in Reference 3.

The values of Tables C-1 and C-2 indicate that intermediate use of CFC-11 and CFC-12 averaged about 5 percent of total production for the historical period. Small quantities of both CFCs are used in-house as refrigerants. Although there are no supporting data, they may also be used consumptively as chemical intermediates.

For the same period, according to Table C-3, CFC-22 intermediate use represented approximately 28 percent of production. This CFC is used as one component of the refrigerant, CFC-502, and this would account for part of the intermediate use. In 1976, approximately 10 million pounds of CFC-502 were sold as a refrigerant. About half of this, or 5 million pounds, was CFC-22 and half was CFC-115. Some CFC-22 is also converted to TFE which is used in the manufacture of teflon. This apparently accounts for the balance of CFC-22 intermediate use.

Table C-1

CFC-11 APPORTIONMENT--1970-1977

(millions of pounds)

Year	Production	Intermediate Use	Sales	Emissions[a]	Exports[b]	Available For Use[c]
1970	244	7	237	5	12	220
1971	258	21	237	5	12	220
1972	300	14	286	6	14	266
1973	334	5	329	7	16	306
1974	341	20	321	6	16	299
1975	270	16	254	5	13	236
1976	256	17	239	5	12	222
1977	213	16	197	4	10	183

[a]Emissions cited in the table are those resulting from storage, packaging, and transport and do not include CFC emitted in the production process.

[b]Assumed to be 5 percent of sales.

[c]The figures in this column represent sales minus emissions minus exports. See Appendix D for more detail.

Table C-2

CFC-12 APPORTIONMENT--1970-1977

(millions of pounds)

Year	Production	Intermediate Use	Sales	Emissions[a]	Exports[b]	Available For Use[c]
1970	375	19	356	7	18	331
1971	390	18	372	7	19	346
1972	439	20	419	8	21	390
1973	489	25	464	9	23	432
1974	487	38	449	9	22	418
1975	393	18	375	8	19	348
1976	393	22	371	7	19	345
1977	358	18	340	7	17	316

[a]Emissions cited in the table are those resulting from storage, packaging, and transport and do not include CFC emitted in the production process.

[b]Assumed to be 5 percent of sales.

[c]The figures in this column represent sales minus emissions minus exports. See Appendix D for more detail.

Table C-3

CFC-22 APPORTIONMENT--1970-1977

(millions of pounds)

Year	Production	Intermediate Use	Sales	Emissions[a]	Exports[b]	Available For Use[c]
1970	100	27	73	1	4	68
1971	112	32	80	2	4	74
1972	123	43	80	2	4	74
1973	136	39	97	2	5	90
1974	141	29	112	2	6	104
1975	132	38	94	2	5	87
1976	170	44	126	3	6	117
1977	179	50	129	4	6	119

[a]Emissions cited in the table are those resulting from storage, packaging, and transport and do not include CFC emitted in the production process.

[b]Assumed to be 5 percent of sales.

[c]The figures in this column represent sales minus emissions minus exports. See Appendix D for more detail.

Table C-4

CFC-113 APPORTIONMENT--1970-1977

(millions of pounds)

Year	Production[a]	Sales[a]	Available For Use[a]
1970	43	41	41
1971	44	42	42
1972	51	49	49
1973	68	65	65
1974	72	69	69
1975	72	69	69
1977	84	80	80

[a]The CFC-113 apportionment was accomplished differently from other CFCs. The method is described in Reference 8.

Table C-5

CFC-114 APPORTIONMENT--1970-1977

(millions of pounds)

Year	Production	Intermediate Use[a]	Sales	Emissions[b]	Exports[c]	Available For Use[d]
1970	35	6	29	1	1	27
1971	39	6	33	1	2	30
1972	43	6	37	1	2	34
1973	43	6	37	1	2	34
1974	44	6	38	1	2	35
1975	39	6	33	1	2	30
1976	37	6	31	1	2	28
1977	25	6	19	0	1	18

[a] Intermediate use for the historical period averaged about 6 million pounds per year.

[b] Emissions cited in the table are those resulting from storage, packaging, and transport and do not include CFC emitted in the production process.

[c] Assumed to be 5 percent of sales.

[d] The figures in this column represent sales minus emissions minus exports. See Appendix D for more detail.

For CFC-113, industry sources indicate that intermediate use is negligible as indicated in Table C-4. For CFC-114, the values of Table C-5 show that intermediate use averaged approximately 16 percent of production for the period. Most of the CFC-114 used in this way is converted to CFC-115, one component of CFC-502. As discussed before, about 5 million pounds of CFC-115 were produced in 1976 for CFC-502. The CFC-114 requirement was about 6 million pounds which agrees exactly with the 1976 value for CFC-114 intermediate use in Table C-5.

Emissions, as given in the tables, represent 2 percent of sales, while exports represent 5 percent.

AEROSOL USE

References 1 and 4 claim that, in 1973, 237 million pounds of CFC-11, 249 million pounds of CFC-12, and 25 million pounds of CFC-114 were used as propellants. Information provided by a knowledgeable industry source indicates that, although the total amount of CFC used in this way is in relatively good agreement with Reference 4, the mix was quite different. According to these data, 1973 aerosol use accounted for 170 million pounds of CFC-11, 265 million pounds of CFC-12, and 45 million pounds of CFC-114.

Since the information of the industry source is more recent and also more complete (values are given for 1973 through 1979), it will be adopted here. Unfortunately, no data for 1970 to 1972 are available. Reference 4 states that the aerosol application accounted for 45 and 49 percent of total CFC use in 1968 and 1973 respectively. The implication is that aerosol uses of the CFCs were slightly less in 1970 than 1973 on a percentage basis.

Table C-6 lists the annual amount of CFC-11, CFC-12, and CFC-114 available for use and the amounts used in aerosols and nonaerosol applications. The data in this table were derived in the following manner:

1. The CFC available was taken from Tables C-1, C-2, and C-5 of this work.

2. The industry-supplied figures for CFC-11 and CFC-12 aerosol use were adopted for 1973 through 1977. This source gives ranges for 1974 and 1975, and the midpoints of these ranges are given in Table C-6.
3. For 1970, 1971, and 1972, it was assumed that 54 percent of CFC-11, 60 percent of CFC-12, and 96 percent of CFC-114 were used in aerosol applications.
4. Figures for nonaerosol end use are the difference between the total amount of CFC available and the amount used in aerosol applications.

Table C-6 illustrates a number of points. CFC used as a propellant began declining in 1975, probably in anticipation of the propellant ban. In addition, the amount of the three CFCs available for use (and thus their production and sales) has also declined. As was mentioned previously, this is not the case for CFC-22 and CFC-113, both of which were not widely used as propellants.

Tables C-1 through C-6 are summarized in Table IV-1 of Section IV and compared with nonaerosol end use data from Reference 8.

Table C-6

CFC AEROSOL AND NONAEROSOL END USE--1970-1977

(millions of pounds)

Year[a]	CFC-11			CFC-12			CFC-114		
	Available For Use	Aerosol	Non-Aerosol	Available For Use	Aerosol	Non-Aerosol	Available For Use	Aerosol	Non-Aerosol
1970[b]	220	119	101	331	199	132	27	26	1
1971[b]	220	119	101	346	207	139	20	29	1[c]
1972[b]	266	142	124	390	232	158	34	33[c]	1[c]
1973	306	170	136	432	265	167	34	33[d]	1[c]
1974	299	168	131	418	235	183	35	34[e]	1[c]
1975	236	143	93	348	186	162	30	29	1
1976	222	123	99	345	156	189	28	26	2
1977	183	70	113	316	91	225	18	14	4

[a]Total CFC here does not include CFC-22 or CFC-113 since both are used exclusively in nonaerosol applications.

[b]The values for these three years are constructed numbers. See the text for more detail.

[c]Values do not represent the percentages indicated due to rounding errors.

[d]The industry source reports that 45 million pounds of CFC-114 were used in aerosol applications in 1973. It is unlikely, given the emissions, exports, captive, and in-house uses, that the amount available for use could be as high as 45 million pounds. Reference 1 gives 1973 CFC-114 aerosol use as 25 million pounds. It will be assumed here that 96 percent of the CFC-114 available for use was used in aerosol applications in 1973.

[e]The industry source reports that 39 to 40 million pounds of CFC-114 were used in aerosol applications in 1974. Since the total amount available for use is not that high, it will again be assumed that 96 percent of the CFC-114 went toward aerosol applications.

Appendix D

CALCULATING CFC NONAEROSOL END USE

This appendix describes a model for calculating the amount of each CFC available for nonaerosol use based on production and/or sales figures. Between the time the CFC is produced and the time it is used, the CFC has various destinations. Each of these destinations was discussed in detail in Section IV, and a summary is given here.

1. Production Emissions

   Emissions occur during the production process prior to the reporting of production figures. The production figures represent 98 percent of the CFC originally manufactured.

2. Storage, Packaging, and Transport Emissions

   These emissions occur sometime between production and use of the CFC. For convenience, they amount to 2 percent of the reported sales figures.

3. Intermediate Use

   This use of the CFC accounts for part of the difference between reported production and sales figures, and its magnitude varies among the CFCs. Since this use involves converting the CFC to another chemical compound, emission of the CFC itself is unlikely to occur.

4. In-House Use

   This use, together with captive use, accounts for the difference between the reported production and sales figures. In-house use involves use of the CFC itself by the producer. Some emissions may occur during this use, but will be considered negligible.

5. Market Inventories

Inventories may amount to 6 percent of each year's sales. Since inventories in successive years frequently cancel one another, they are not considered here.

6. Exports

CFC exports are assumed to be 5 percent of sales.

THE MODEL

The quantities for establishing the historical material balance can be defined for a given year as follows:

M = the amount of CFC originally manufactured.
P = the reported CFC production.
PE = the quantity of CFC emitted during the production process.
S = the reported CFC sales.
SPTE = the quantity of CFC emitted during storage, packaging, and transport.
E = the amount of CFC exported.
CU = the quantity of CFC used as an intermediate.
IU = the quantity of CFC used in-house by the producers.
AU = the amount of CFC used in aerosol applications.
EU = the amount of CFC used in nonaerosol applications.

The relationships relating one variable to another are as follows:

$$P = 0.98\ M$$
$$PE = 0.02\ M$$
$$P - S = CU + IU$$
$$SPTE = 0.02\ S$$
$$E = 0.05\ S$$

The total amount of CFC available for end use in a particular year is as follows:

$$EU = M - PE - SPTE - CU - IU - E - AU \qquad (C\text{-}1)$$

Since production figures for CFC are often available, this can be rewritten:

$$EU = P - SPTE - CU - IU - E - AU$$
$$= 0.93\ (P - CU - IU) - AU \qquad (C\text{-}2)$$

If, alternatively, sales figures are given, the relationship is simplified to:

$$EU = S - 0.07\ S - AU$$
$$= 0.93\ S - AU \qquad (C\text{-}3)$$

All of these relationships apply to CFC-11, CFC-12, CFC-22, and CFC-114, but not to CFC-113. The material balance for CFC-113 was addressed in more detail in Reference 8.

AN EXAMPLE

As one sample application of the model, the production figures of Table VI-2 can be used to determine the CFC available for end use. For CFC-12, 1990 production is estimated at 365 million pounds. Intermediate and in-house use of CFC-12 in 1976, the reference year, were about 3 percent of production, and will be assumed to remain at that level through 1990. Since propellant use has been banned, AU is zero. Thus, using Equation C-3, the amount of CFC-12 available for end use in 1990 is 327 million pounds which agrees with the end use value in Table VI-2.

End use of CFC-11, CFC-22, and CFC-114 for 1990 can be determined in the same manner by using the 1976 level of intermediate and in-house use. CFC-113 was treated somewhat differently and is discussed in detail in Reference 8.

The model is useful for estimating future production, sales, or end use when one of the three variables is known. However, some of the assumptions on which the model was based may not hold in the future. For example, exports may not remain at 5 percent of sales, or imports may increase. Nevertheless, the model does provide the framework for calculating future production or end use by simply varying the export level or including imports.

Appendix E

ALLOCATION OF CAPACITY

The purpose of this appendix is to evaluate the applicability of a technique for allocating capacity available for producing each CFC. We first present historical total capacity estimates based on an industry "rule of thumb." We then show a capacity allocation to each CFC for 1977.

HISTORICAL TOTAL CAPACITY

We have been told by knowledgeable industry sources that plant capacities historically remained approximately 15 percent ahead of production requirements.[1] Since production of the five CFCs represents about 99 percent of total CFC production, the applicability of this rule can easily be determined.

Total historical production, obtained by summing the values of Tables III-1 through III-3, is given in Table E-1 with the implied capacity according to the "rule of thumb" given above.

The 1977 implied capacity value agrees very well with the estimated 1978 total capacity of 1060 million pounds given in Table V-1. The historical trend in total production may also lend credence to the difference in capacities specified by the two references in that table. Reference 4's total capacity of 1195 million pounds would have been adequate for the demand prior to 1973. Additional capacity was obviously necessary to meet the increased production levels of 1973 and 1974. Reference 1's higher total capacity of 1435 million pounds could reflect the fact that further capacity was added in this period.

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[1] The design capacity of a plant is often not a true indication of the production capability. Frequently, with relatively modest capital expenditures, a plant may have the capability to actually produce at as much as 200 percent of design capacity. It should be kept in mind that the use of design capacity for production allocation does have limitations. The claim by industry that capacities have historically remained 15 percent ahead of production may be a useful relationship for the long-term situation; nevertheless, it is sometimes true that short-term production can far exceed plant design capacity.

Table E-1

CFC PRODUCTION AND CAPACITY--1970-1977

(millions of pounds)

Year	Production	Implied Capacity
1970	797	917
1971	843	969
1972	956	1099
1973	1070	1231
1974	1085	1248
1975	899	1034
1976	928	1067
1977	859	988

The decline in production which began in 1975 probably led to the plant closings which are reflected in 1978 estimated total capacity. In any case, the 15 percent rule of thumb provided by industry sources seems to give a fairly good estimate of total capacity given the total historical production data, and it is therefore useful for predicting future capacity based on production projections.

It is necessary to have information detailing the plant capacity of each producer by individual CFC in order to assess and possibly separate the effects on the different firms of limitations of emissions from the various end use areas. Unfortunately, no current data of this type exist. However, some of the references do provide information that can be used to allocate the current industry capacity for each CFC to a particular firm.

Plants designed to produce CFC-113/CFC-114 are not presently used to produce the three other CFCs.[1] However, since these plants have the most stringent construction requirements, they could, with some investment, be converted to CFC-11/CFC-12 or CFC-22 production. The opposite, however, does not obtain. CFC-11/CFC-12 and CFC-22 plants are constructed for less stringent processing conditions and, therefore, they cannot, without virtually being rebuilt, be converted to produce CFC-113/

[1] Some storage facilities, however, can be used interchangeably for CFC-11/CFC-12 and CFC-113/CFC-114.

CFC-114. Thus, it seems reasonable to assume that currently existing plants either produce CFC-113/CFC-114 or the other three CFCs.

Reference 1 indicates that DuPont's one remaining CFC-113/CFC-114 plant has 100 million pounds of capacity. This reference also assigns 100 million pounds to one of Allied's locations where all five CFCs are produced. This is the only Allied facility which presently produces CFC-113/CFC-114. According to industry sources, Allied's estimated CFC-113/CFC-114 capacity is about 50 million pounds. Total 1977 CFC-113 and CFC-114 production was 109 million pounds, which, using the "rule of thumb," would imply a combined capacity of 125 million pounds for the two producers. This does not differ drastically from the industry source estimate of 150 million pounds. The current 1978 estimate of total CFC-113/CFC-114 capacity by industry sources will be adopted here, leaving 910 million pounds of capacity for CFC-11/CFC-12 and CFC-22.

It is difficult to separate CFC-11/CFC-12 from CFC-22 capacity. Some plants were designed as "campaign plants." Such plants are capable of producing either CFC-11/CFC-12 or CFC-22 simply by varying the feed. Thus, design capacity itself is not meaningful in this case. What is meaningful is the portion of design capacity which was used annually to produce CFC-22.

It will be assumed that the 910 million pounds of capacity remaining after CFC-113/CFC-114 capacity has been taken into account can be allocated according to the relative amounts of CFC-11, CFC-12, and CFC-22 produced in 1977.[1] It will also be assumed that the 150 million pounds of CFC-113/CFC-114 capacity can be apportioned according to the relative 1977 production of each. Table E-2 shows the results of this allocation scheme.

Total 1977 CFC-22 production was 179 million pounds. Using the 15 percent rule of thumb, this latter value implies a capacity of about

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[1]Although apportioning individual CFC capacities to plants producing more than one CFC is not strictly correct, it does provide a rough idea of capacity share devoted to each.

Table E-2

1977 CFC CAPACITY
(millions of pounds)

CFC	Annual Capacity	Percent of Total
CFC-11	259	24
CFC-12	434	41
CFC-22	217	21
CFC-113	115	11
CFC-114	35	3
TOTAL	1060	100

205 million pounds for CFC-22, which agrees well with the value of Table E-2. Actual 1977 combined production of CFC-11 and CFC-12 was 571 million pounds. Again, using the "rule of thumb," this would imply a capacity of about 660 million pounds which, again, agrees fairly well with the amount estimated in Table E-2.

Appendix F

CFC SALES ESTIMATES

The estimates of Table V-6 understate CFC sales for Racon in particular and probably for the other producers as well.

The factor that is probably most responsible for the understatement of the sales is intermediate CFC use. The figures for the sales value of CFC-11, CFC-12, and CFC-22 given in Reference 3 do not include sales of CFC used as an intermediate. For example, much of the CFC-22 that is produced is used as an intermediate in a process for manufacturing teflon which is marketed by DuPont. Clearly, part of the sales of teflon is attributable to CFC-22. The same applies to CFC-11, CFC-12, and CFC-114 which are also used to a lesser extent as intermediates.

Perhaps a more accurate estimate of sales allocation to each firm could be made by assuming that all the CFC that is produced is sold at the average unit selling price for each CFC. Apportionment could still be accomplished on the basis of portion of capacity held but would include all the CFC that is produced.

Table F-1 presents the 1977 CFC sales allocation by firm based upon the production of each CFC .

Table F-1

1977 CFC SALES FROM PRODUCTION FIGURES

(millions of dollars)

Producer	CFC-11	CFC-12	CFC-22	CFC-113	CFC-114	Total
Allied	15.9	30.1	24.5	15.0	5.4	90.9
DuPont	41.2	80.1	63.6	30.4	10.9	226.2
Kaiser	6.5	12.9	9.8			29.2
Pennwalt	7.2	14.3	11.0			32.5
Racon	1.5	5.7	13.4			20.6
TOTAL	72.3	143.1	122.3	45.4	16.3	399.4

Comparing the total sales in Table F-1 with that of Table V-5 shows that the allocation scheme based on production increases the total sales by about 15 percent. In addition, Racon's sales, given in Table F-1, are higher and thus closer to the actual sales of $29.7 million. In fact, the sales of all firms are higher in Table F-1 than they are in Table V-5.

Racon's sales are still too low, probably for a number of reasons. First, the sales allocation scheme, whether based on the amount of CFC produced or the amount sold, assumes that sales is proportional to the fraction of total industry capacity held by a particular firm. Racon may run its plants at higher capacity and therefore be responsible for a larger percentage of total sales. For this to be true, however, it is required that one or more of the other producers' sales be less than that indicated in Table F-1. That is, if Racon's sales share is higher, since the total sales is constant, sales of the other producers must be lower. To illustrate the sensitivity of the allocation scheme, we note that if Racon actually sells 15 percent of the CFC-22 rather than 11 percent as indicated by the capacity apportionment, then Racon's total sales in Table F-1 would increase to $25.6 million which is much closer to Racon's actual sales. If Racon's share of CFC-11 and CFC-12 sales were also increased slightly, it is easy to see how the actual sales of the firm could be realized.

Another factor that may contribute to the low estimate of Racon's sales is sales of azeotropes.[1] Racon markets two azeotropes, CFC-500 and CFC-502, which are sold as refrigerants.[2] The price of CFC-502 is nearly three times that of CFC-12. On this basis, if only a few million pounds of Racon's CFC-22 were sold as one component of the azeotrope R-502 instead of in the pure form, Racon's CFC sales would be much larger. Since azeotrope formulation is accomplished with CFC used as an intermediate, this same factor may also contribute to understatement of the other producers' sales.

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[1] Azeotropes are combinations of two or more chemicals.

[2] CFC-500 consists of 74 percent CFC-12 and 26 percent CFC-152a by weight.

Probably the most important reason for Racon's low sales estimate involves prices. The sales value of Reference 3 for CFC-11, CFC-12, and CFC-22 is a total industry value. This number divided by the amount sold gives an average industry selling price but does not necessarily reflect the average selling price for a particular firm. Racon may have sold less of these CFCs in large quantities and more in smaller quantities with higher prices. To emphasize the possible variations in price, a 1978 price list for CFC-11, according to packaging for refrigeration, is given in Table F-2.

The values of this table indicate that price is highly influenced by the type of packaging and the total amount delivered. CFC-11 is also used in the foam-blowing industry, and it is likely that a price list of CFC-11 for this application would differ significantly from that shown in Table F-2.

Table F-2

1978 PRICE LIST--CFC-11

(cents per pound delivered)

Container	Price
Bulk	40
One Ton Cylinder	52
650 Pound Drum	50
200 Pound Drum	54
100 Pound Drum	61
30 Pound Pressurized Cylinder	80

In deriving the values of Table V-6, a unit value of about 34 cents per pound was used for CFC-11 in 1977.[1] This price is lower than any of the prices in Table F-2, which could indicate a price increase occurred from 1977 to 1978. Nevertheless, the table serves to emphasize that there is a large variation in the prices at which the CFC is sold and that caution must be exercised when using the numerous quoted prices.

[1] This unit value is calculated by dividing CFC sales value by quantity sold.

The final factor which may contribute to sales underestimates involves the CFC-113 and CFC-114 prices. Racon purchases these two CFCs from their producers and sells them as refrigerants. Racon's purchase is probably at bulk price and the subsequent sales are likely in smaller packages at higher prices. These sales also have not been included in Racon's calculated sales in Table V-6.

Because we know that 100 percent of Racon's sales derives from sales of CFCs, we know that Table V-6 underestimates Racon's sales. Some of the factors presented here provide possible reasons for the low estimates. The fact that intermediate use of the CFCs is not included in the sales values of Table V-6 implies that sales for all producers are probably understated.

Appendix G

PRECURSOR CHEMICAL PRODUCERS

In this appendix, we identify the producers of the precursor chemicals, and apportion precursor chemical production to each producer based on capacity. Each precursor chemical identified in Section II as being highly dependent on CFC manufacture is treated in turn.

CCl_4

As Appendix B indicates, almost all of the CCl_4 which was produced historically has been used in CFC manufacture. Limitation of CFC-11 and CFC-12 production would cause all CCl_4 manufacturers to suffer.

Reference 1 gives the 1976 annual capacity of CCl_4 as 1325 million pounds, while recent industry estimates indicate a lower value of 1205 million pounds. The 1977 production of CCl_4 for CFCs totaled 708 million pounds, 243 and 465 million pounds of which went toward CFC-11 and CFC-12 manufacture, respectively. Table G-1 shows the CCl_4 producers and their capacities from recent industry estimates.

The 1977 production of CCl_4 by each firm for CFC-11 and CFC-12 is also given in the table. Allocation of the production was based on a number of assumptions. First, for DuPont, the only CFC producer listed, it was assumed that CCl_4 production was equal to the amount needed for its own CFC-11 and CFC-12 manufacture. Vulcan materials is the precursor chemical supplier for Racon, and CCl_4 production was assumed sufficient for Racon's CFC manufacturing needs. Production allocation to the other two firms, Dow and Stauffer, was accomplished on the basis of the relative capacity share held.

It should be mentioned here that CCl_4 "capacity" is somewhat misleading since much of this chemical is manufactured with the coproduct C_2Cl_4. Thus, in a sense, some portions of CCl_4 and C_2Cl_4 capacity are interchangeable.

Table G-1

CCl_4 PLANT CAPACITY--1977
(millions of pounds)

Producer	Annual Capacity	1977 CCl_4 Production For CFC-11	1977 CCl_4 Production For CFC-12
Dow Chemical	290 (24)	26	50
DuPont	300 (25)	139	260
FMC[a]	280 (23)	53	98
Stauffer Chemical	225 (19)	20	38
Vulcan Materials	110 (9)	5	19
TOTAL	1205 (100)	243	465

[a]Joint venture with Allied which apparently shut down in mid-1979.

According to Table III-5, 88 percent of the CCl_4 manufactured in 1977 was used for CFC production. The total amount of CCl_4 produced that year was 809 million pounds. Using the same 15 percent rule of thumb as applied to CFC capacity implies a 1977 CCl_4 annual capacity of about 930 million pounds.[1] This is smaller than the total 1977 capacity indicated in Table G-1. In 1974, CCl_4 production was 1163 million pounds, which leads to a required capacity of about 1340 million pounds. This value agrees well with the total capacity of Reference 1, but is higher than the industry estimates of Table G-1. It may be that some plants have been closed since CCl_4 production peaked in 1974 or it may be that C_2Cl_4 capacity has been included in these estimates. Nevertheless, current CCl_4 capacity is apparently underutilized.

One very interesting point concerning CCl_4 is the extremely large difference between the production and sales reported in Reference 3. The 1976 total CCl_4 production was 857 million pounds

[1]If FMC did, indeed, close its plant in mid-1979, the total annual CCl_4 capacity would be 925 million pounds, which agrees well with the implied capacity for current production.

while the sales total was only 459 million pounds, which indicates a captive use of 398 million pounds, 46 percent of the amount produced. Since most CCl_4 is used to manufacture the CFCs, it might be expected that the CCl_4 is used captively by the producers themselves for this purpose.

According to Table G-1, DuPont and Allied (with FMC) are the only CFC producers who also manufacture CCl_4. Although Vulcan Materials is the precursor chemical supplier for Racon, its production would probably be reported in the total sales figures of Reference 3. Combined CCl_4 production by FMC and DuPont, from Table G-1, is about 550 million pounds, which is somewhat higher than the captive use from Reference 3. However, it does not seem unreasonable to assume that much of the CCl_4 is used captively by the CFC producers themselves.

HF

Appendix B gives the quantities of HF used in CFC-11, CFC-12, CFC-22, CFC-113, and CFC-114 manufactured in 1977 as 32, 122, 86, 28, and 12 million pounds respectively. Reference 1 indicates that in 1976 there were nine HF producers with a combined annual capacity of 738 million pounds. Recent industry estimates give a current total capacity of 683 million pounds. These capacities and the producers who hold them are given in Table G-2 with an apportionment of the HF to each producer.

Industry sources claim that Alcoa, Kewanee Industries, Ashland Oil, and Stauffer Chemical produce no HF for CFC manufacture.[1] Thus, for these producers, Table G-2 shows no production of HF for CFCs. The sources further indicate that Essex Chemical devotes about 50 percent of its HF production to CFC needs. All the other producers produce most, if not all, of their HF for CFC manufacture. For the remaining producers, the production apportionment given in Table G-2 again assumes that production is proportional to relative capacity.

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[1] Some HF for CFC manufacture is imported from Mexico, but this will not be considered here.

Table G-2

HF PLANT CAPACITY--1977

(millions of pounds)

Producer	Annual Capacity (Percent of Total)		CFC-11	CFC-12	CFC-22	CFC-113	CFC-114
	Total	For CFC Manufacture					
Allied	169	169 (35)	11	43	30	10	4
Alcoa	110	--	--	--	--	--	--
DuPont	150	150 (31)	10	38	27	9	4
Essex Chemical	22	11 (2)	1	2	2	1	0
Kewanee Industries	36[a]	--	--	--	--	--	--
Kaiser	100[b]	100 (21)	7	26	18	6	3
Ashland Oil	10	--	--	--	--	--	--
Pennwalt	50	50 (11)	4	13	9	3	1
Stauffer Chemical	36[b]	--	--	--	--	--	--
TOTAL	683	480 (100)	33[c]	122	86	29[c]	12

[a]Although Reference 1 gives Kewanee Industries' annual capacity as 100 million pounds, both References 4 and 6 give 36 million pounds. Reference 1's total of 738 million pounds is not correct unless this company's capacity is 36 million pounds.

[b]Industry sources claim that both Kaiser and Stauffer will shortly close their HF plants.

[c]Due to rounding, the values do not add to the actual total given in the text.

Racon is the only CFC producer who does not manufacture HF. However, the firm is now wholly owned by Essex, which does produce HF. The four CFC producers--Allied, DuPont, Kaiser, and Essex (via Racon)--together hold 72 percent of the total HF capacity. Industry sources have indicated that Kaiser and Stauffer will shortly close their HF manufacturing facilities. There are, however, no published data which confirm this.

Since Allied and DuPont are the only producers of CFC-113 and CFC-114, it might be reasonable to assume that only HF produced by these two companies is used to manufacture CFC-113 and CFC-114. Unfortunately, the situation is not this straightforward. Although the mandate of this study does not include a detailed examination of the interrelationship among the various chemicals producers, many informal conversations with industry sources have led us to believe that there exists among chemical producers a high degree of mutual "cooperation." That is, companies often accommodate the shortage or surplus of a particular chemical on the part of one company by a sale or purchase.[1] Thus, although DuPont and Allied may use their own HF for CFC-113 and CFC-114 manufacture, they probably also use some manufactured by other producers.

According to Appendix B, 1977 HF production for CFCs totaled 280 million pounds. Assuming that this represents 46 percent of total HF production (as indicated for 1976 in Table III-5), and using the 15 percent rule of thumb as before, the implied 1977 total HF capacity would be about 700 million pounds. This agrees well with the value given in Table G-2.

$CHCl_3$ AND C_2Cl_4

Appendix B gives the quantities of C_2Cl_4 which went toward CFC-113 and CFC-114 manufacture in 1977 as 77 and 25 million pounds respectively. Also, according to Appendix B, 260 million pounds of $CHCl_3$ were used in CFC-22 production that year.

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[1] This is, in fact, widely practiced for the purpose of saving freight.

Reference 4 is the only reference to list the producers and the corresponding capacities for $CHCl_3$ and C_2Cl_4. Unfortunately, this information is dated 1973, and some changes have taken place since that time. However, these data together with recent data from industry sources should be adequate. Table G-3 shows the producers, their capacities, and the amount of $CHCl_3$ and C_2Cl_4 estimated to have been used in CFC-22 and CFC-113/CFC-114 production in 1977.[1] The table indicates that $CHCl_3$ is produced by Allied, but not DuPont, and C_2Cl_4 is produced by DuPont, but not Allied.

Appendix B indicates that total 1977 production of $CHCl_3$ and C_2Cl_4 were 302 and 603 million pounds respectively. These production levels imply total capacities of about 350 million pounds for $CHCl_3$ and 690 million pounds for C_2Cl_4 according to the 15 percent rule of thumb. The agreement with the $CHCl_3$ capacity of Table G-3 is fairly good, while that for C_2Cl_4 is very poor. In the latter case, either the data of Table G-3 are not current or the C_2Cl_4 capacity is far in excess of that necessary for current production levels. One factor that may account for the discrepancy is that some of the C_2Cl_4 and CCl_4 are co-produced and many of the plants that produce C_2Cl_4 may have been originally sized for CCl_4 production. A comparison of C_2Cl_4 and CCl_4 producers shows that four--Dow, DuPont, Stauffer, and Vulcan Materials--are common to both. The $CHCl_3$ production has been apportioned to Allied and Vulcan Materials based on the amount of CFC-22 produced by Allied and Racon. The remaining producers were allocated $CHCl_3$ production according to the portion of capacity held. For C_2Cl_4, DuPont's production was assumed equal to the need for CFC-113 and CFC-114 manufacture, and the other producers were allocated production according to the percent of capacity held.

CS_2

The producers of CS_2 and their capacities are given only in Reference 6 for an unspecified year. Table G-4 shows this informa-

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[1] Capacity of both C_2Cl_4 and $CHCl_3$ are somewhat elusive in that the former is produced as a co-product with CCl_4 and the latter with methylene chloride (CH_2Cl_2).

Table G-3

$CHCl_3$ AND C_2Cl_4 PLANT CAPACITY--1977
(millions of pounds)

Producer	Annual Capacity (Percent)	Production For CFC-22	Annual Capacity (Percent)	Production For CFC-113	Production For CFC-114
Allied	30 (10)	52	--	--	--
Diamond Shamrock	18 (6)	14	160 (14)	4	1
Dow Chemical	130 (44)	104	290 (24)	8	2
DuPont	--	--	160 (14)	50	17
Ethyl Corporation	--	--	50 (4)	1	0
Occidental/Hooker Chemical	--	--	50 (4)	1	0
PPG	--	--	200 (17)	5	2
Stauffer	75 (26)	60	70 (6)	2	1
Vulcan Materials	40 (14)	29	200 (17)	5	2
TOTAL	293 (100)	259[a]	1180 (100)	76[a]	25

[a]Values listed here may not add to the total given in the text due to rounding.

tion and the apportionment of the 1977 CS_2 production of 51 and 87 million pounds for CFC-11 and CFC-12 respectively, to each producer. Although Pennwalt and PPG do produce CS_2, they do not use CS_2 to manufacture CCl_4 for CFC-11 and CFC-12, according to industry sources. Thus, the apportionment of CS_2 in Table G-4 only includes FMC and Stauffer. It was assumed that the FMC production of CS_2 was sufficient for the CCl_4 requirements needed to manufacture CFC-11 and CFC-12 by Allied Chemical. The balance of CS_2 production was allocated to Stauffer.

Appendix B shows that 140 million pounds of CS_2 went toward CFC-11/CFC-12 production in 1977. Assuming that this amount represents 26 percent of total CS_2 production (given in Table III-5 for 1974) and that the 15 percent rule of thumb also holds, a 1977 capacity of about 620 million pounds is implied. This value is quite a bit less than the figure shown in Table G-4. Perhaps the latter capacity estimate is not recent. The 1974 total production of CS_2 was 772 million pounds, which agrees well with the capacity value of Table G-4. It is possible that reduced CFC-11/CFC-12 production since 1974 may have caused some CS_2 plant closings in recent years.

Table G-4

CS_2 PLANT CAPACITY--1977

(millions of pounds)

	Annual Capacity (Percent of Total)		CS_2		
Producer	Total	For CFCs	For CFC-11	For CFC-12	Total
FMC	180 (21)	180 (23)	28	51	79
Pennwalt	10 (1)	--	--	--	--
PPG	60 (7)	--	--	--	--
Stauffer	600 (71)	600 (77)	20	41	61
TOTAL	850 (100)	780 (100)	48	92	140

This, however, is only speculation, and it may be that CS_2 capacity is simply in excess of that required currently. Industry sources have mentioned the possibility that Stauffer has closed or may close its plant in the near future.

Cl_2

This chemical, since it is used both as a preliminary and intermediate precursor, is more complicated to assess. According to Reference 4, intermediate use of chlorine accounts for about 47 percent of the amount produced in 1973.

This reference also provides a list of 1975 Cl_2 producers and their capacities. This list is shown in Table G-5 with the relative capacity share of each producer and the estimated 1977 Cl_2 production devoted to each CFC. The amounts of Cl_2 used to produce CFC-11, CFC-12, CFC-22, CFC-113, and CFC-114 in 1977 taken from the text here were 351, 672, 420, 97, and 33 million pounds, respectively. Table G-5 indicates that Allied, DuPont, Kaiser, and Pennwalt, four of the CFC producers, are involved in Cl_2 production in addition to Vulcan Materials, the raw materials supplier for Racon.

It is likely that the CFC manufacturers listed in Table G-5 (including Vulcan Materials, the supplier for Racon) produced the Cl_2 needed for their CFC production. DuPont, Allied (through the joint venture with FMC), and Vulcan Materials are CCl_4 producers for which Cl_2 is necessary. Thus, the Cl_2 production for CFC-11 and CFC-12 in Table G-5 was allocated to these three producers based on their CCl_4 needs. The balance was allocated to the other producers. Allied and Vulcan Materials also produce $CHCl_3$. The Cl_2 for CFC-22 was apportioned to these two firms according to their $CHCl_3$ needs and the balance to the other producers. The Cl_2 for CFC-113 and CFC-114 was allocated to DuPont for both C_2Cl_4 and direct CFC-113/CFC-114 production and to Allied for CFC-113/CFC-114 production in the same manner.

Table G-5

Cl_2 PLANT CAPACITY--1975
(millions of pounds)

Producer[a]	Capacity (Percent)	For CFC-11	For CFC-12	For CFC-22	For CFC-113	For CFC-114	Total
Dow Chemical	7920 (35)	26	50	109	9	3	197
PPG Industries	2400 (11)	8	15	33	3	1	60
Diamond Shamrock	2304 (10)	8	14	32	3	1	58
Occidental Petroleum	1930 (9)	6	12	27	2	1	48
Allied Chemical	1188 (5)	77	142	84	11	4	318
Olin	1170 (5)	4	7	16	1	0	28
BASF Wyandote	1116 (5)	4	7	15	1	0	27
DuPont	720 (3)	201	376	10	62	21	670
Stauffer Chemical	706 (3)	2	4	10	1	0	17
Pennwalt	684 (3)	2	4	9	1	0	16
FMC	568 (3)	2	4	8	1	0	15
Ethyl Corporation	460 (2)	1	3	6	1	0	11
Kaiser	386 (2)	1	2	5	0	0	8
Shell Oil	270 (1)	1	2	4	0	0	7
Vulcan Materials	270 (1)	7	27	47	0	0	81
B. F. Goodrich	216 (1)	1	1	3	0	--	5
Monsanto	180 (1)	1	1	2	0	--	4
Total	22488 (100)[b]	352[c]	671[c]	420	96[c]	31[c]	1570[c]

[a]About 2380 million pounds of Cl_2 capacity is held by paper companies and others according to Reference 3, and these are not included here.

[b]Because of rounding, the percent values do not add to 100 percent.

[c]Because of rounding, the values do not add to the totals given in the text.

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